

MIT Technology Review

VOL. 119 NO. 6 NOVEMBER/DECEMBER 2016

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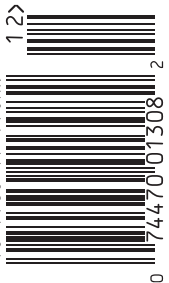
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From the Editor



Industrial policy has “a long and divisive history,” David Rotman writes in “Capitalism Behaving Badly” (page 96). If by crafting industrial policies government’s purpose has been to direct “innovation and growth to achieve a desired objective,” then policies have often failed.

Rotman concedes, “Even advocates of industrial policies acknowledge that they have had a checkered history.” As the Harvard economist Dani Rodrik puts it, while industrial policies have “undoubtedly worked” in a number of countries and could boost green technologies, they have also been associated with expensive fiascos and “white elephants” like the Concorde, a beautiful plane meant to showcase British and French aerospace industries whose every flight lost money. More recently, the failures of President Obama’s stimulus bill, including the bankruptcies of favored companies like the solar-panel manufacturer Solyndra, have shown how hard it is to get industrial policy right.

Another story in this issue suggests why this should be so. “Elon Musk’s House of Gigacards,” by Peter Burrows (page 58), describes the entrepreneur’s audacious plan to have the electric-car company Tesla buy the solar-panel provider SolarCity for more than \$2 billion

in stock. On its face, the plan is alluring: “The combined company will generate power for customers on stylish roofs with embedded solar panels, store it in Tesla battery modules, and, of course, use some of it to power Tesla vehicles.” But Tesla and SolarCity are deeply unprofitable ventures (the former lost \$2.5 billion over the last five years, even more than the latter squandered), and the combination is unlikely to make them profitable.

Tesla and SolarCity benefit from a variety of federal and state policies designed to stimulate demand among potential customers. The cost of Tesla’s cars is reduced by a \$7,500 federal tax credit and by other state incentives (Tesla helpfully lists them all on its website), and it enjoys direct subsidies, including California’s Zero Vehicle Credits. Similarly, SolarCity’s panels were made an attractive investment to homeowners by the federal Solar Investment Tax Credit and by state incentives. These are more or less defensible policies, if governments’ goals are to underwrite the transition to electric vehicles and renewable energy, although the effectiveness of the mechanisms is unknown. The unprofitability of both Tesla and SolarCity is the strategy of their boards and management, indulged by the public markets, and cannot be attributed to incentives and subsidies. (A skeptical observer might wonder, nonetheless, whether such losses would be tolerated in their absence.)

It is the other benefits Tesla and SolarCity enjoy that raise eyebrows. In 2009, during the financial crisis, Tesla was given a \$465 million low-interest loan by the U.S. government, for which taxpayers received no shares and without which the company would not have survived. The case of SolarCity is even more striking. The innovative gigafactory in cloud-socked Buffalo is the direct result of the New York state government’s goal

of creating advanced manufacturing jobs in the city. As an earlier story by Rotman (“Paying for Solar Power,” September/October 2015) explained, “Buffalo is attempting an economic comeback fueled by the state’s Buffalo Billion initiative, a multiyear redevelopment plan spearheaded by Governor Andrew Cuomo ... At the heart of the city’s ambitions is the solar factory, which New York is spending \$750 million to build and equip. SolarCity ... will lease it, essentially for free, and has committed to spending \$5 billion ... over the next decade.” At least some part of the instability of the House of Gigacards is surely attributable to poorly conceived policies.

Smart policy *can* help solve big problems, especially when there has been some kind of market failure—for example, when it comes to capturing the externalities of the greenhouse gases that cause global warming. Many of the world’s most important innovations, including the Human Genome Project and the Internet, were the result of publicly funded research conducted in the context of government strategy. Policy can drive economic growth. But industrial policy gets into trouble when it does some of the things federal and state governments are attempting with Tesla and SolarCity.

First, governments are notoriously poor judges when it comes to picking individual winners: in the absence of well-designed rules and procedures, investment in companies is often the result of political whims and can be hard to end. Second, the goals of a policy must be clearly defined and noncompeting: mixing goals such as creating manufacturing jobs, encouraging solar energy and electric cars, and competing internationally can too easily lead to an end in which none of the goals are realized.

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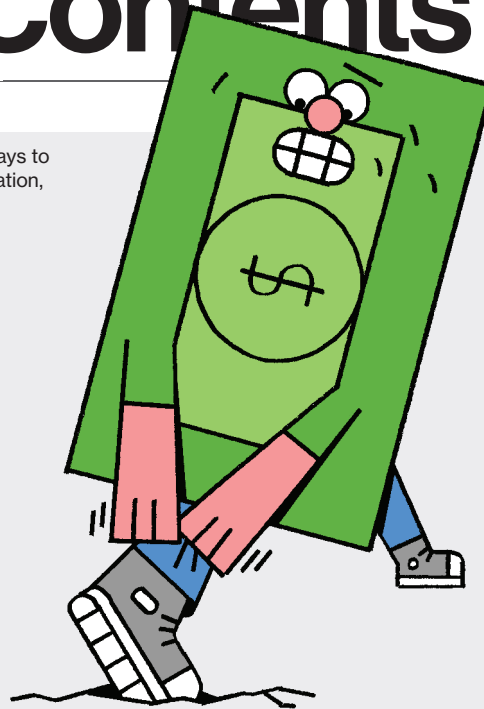
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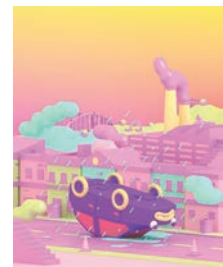


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MIT Technology Review
Volume 119, Number 5



Give AI a Little Bit of Credit, Please
Will Knight's "AI's Language Problem" is more or less a call to action to anybody (like me) who works in artificial intelligence. It's time, Knight declares, for AI to grapple seriously with language understanding. If AI systems can learn to win a difficult game like Go, why can't they yet understand language—which the average child learns effortlessly?

But Knight's not really giving us as much credit as we deserve. And he's being a little too prescriptive about what

answer and you find your meal, I'd say the answer is yes.

Even Knight himself, in his own article, mentions new natural-language-processing capabilities in question answering and image captioning; rapid advances in speech recognition and translation between languages; and parsers that untangle the relationships among words in a sentence. He might also have pointed to search engines, sentiment and opinion analysis, information extraction and summarization from text, assistive devices, and more. For certain dialects within certain languages, we've seen massive progress in language technologies.

The struggle we researchers face is to consistently explain what it means to "understand" formally enough to guide algorithm design and measure how close we're getting to human-level understanding. (And this shouldn't be surprising—everyone has a brain, but our intuitions about how it works don't qualify us to perform brain surgery. Why would it be any different with our capacity for language understanding?)

So how will we know that we've made AI systems that truly understand us? Maybe it's less complicated than we make it out to be. If you ask your self-driving car

doesn't need to revise it much (and when she wins the case).

We're making progress, even if it's not quite as fast as Knight would like it to happen. We're seeing advances in tools whose (at least partial) language understanding complements and augments what humans are capable of processing and understanding. As one of my students once told me, "I want to understand what's in documents without reading them." In finance, health, law, politics, education, science, and many other pursuits, natural language processing is giving us that power.

—Noah A. Smith

**Associate professor of computer science
and engineering, University of Washington**

Will Knight responds:

Professor Smith makes a good point about progress in language understanding in recent years. He's also right when he says machines already "understand" a great deal of what we say. Still, limitations are revealed whenever you try to hold a meaningful conversation with a system like Apple's Siri or Amazon's Alexa, and these show there's a long way to go. The problem will get even more serious as we depend more heavily on machines that have essentially programmed themselves. To take Smith's example, if the driverless car failed to deliver your daughter to the right place, it would be nice to be able to ask what went wrong and to hold a dialogue so the car could get it right the next time. If our goal is AI systems that do our bidding most of the time, we're doing fine. But if we want machines that we can collaborate and cooperate with, they'll need a more sophisticated grasp of language.

Does your phone "understand" you when you ask it where the nearest sushi is? If you find your meal, the answer is yes.

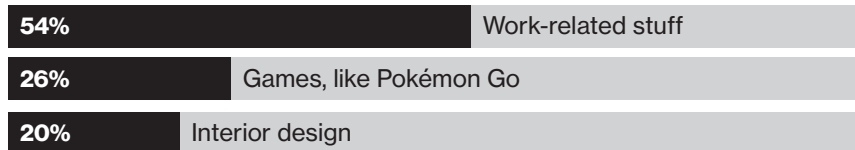
it means to "understand language"—a debate that's raged at least since Turing's day. Does your phone "understand" you when you ask it where the nearest sushi is? If it responds with a good, humanlike

to pick up your kid from day care, you'll know it "understood" you when she's delivered safely to your door. If a lawyer asks her digital assistant to draft a brief for a case, she'll know it "understood" if she

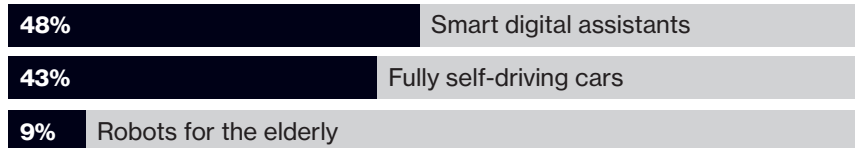
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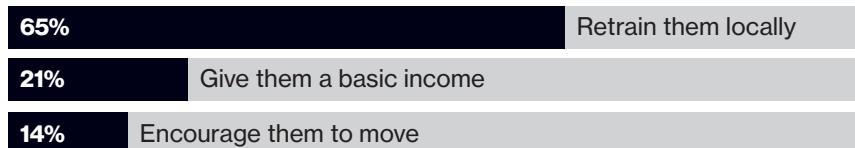
New programs like Google's Tango will make augmented reality more widespread. What would you use AR for?



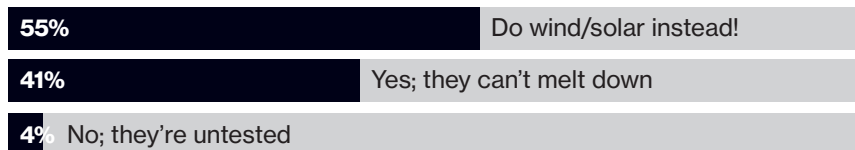
What form of artificial intelligence do you think is most likely to become reality first?



What should we do to help people, like coal miners, whose livelihoods will be overturned by global warming?

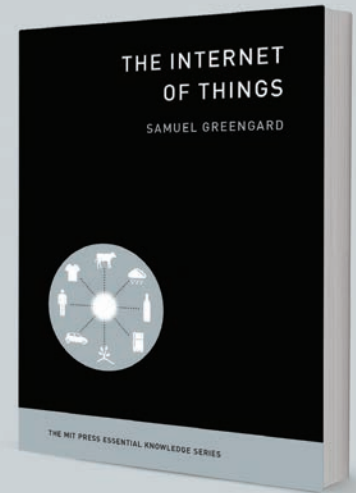


Nuclear power is a steady source of carbon-free power. Should we build more of the newly designed, safer reactors?



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Views



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Michael Mandel



Maureen Hand

ARTIFICIAL INTELLIGENCE

Deep Driving

A revolutionary AI technique is about to transform the self-driving car.

When the Google self-driving-car project began about a decade ago, the company made a strategic decision to build its technology on expensive lidar and detailed mapping. Even today, Google's self-driving technology still relies on those two pillars. While that approach is great up to a point—we have good algorithms for using lidar and camera data to localize a car on the map—it's still not good enough. Driving on complicated, ever-changing streets involves perception and decision-making skills that are inherently uncertain (see “Your Driverless Ride Is Arriving,” p. 34).

Now an artificial-intelligence technology called deep learning is being used to address the problem. Rather than using the old method of hand-coded algorithms, we can now use systems that program themselves by learning from examples of how a system ought to behave in response to an input. Deep learning is now the best approach to most perception tasks, as well as to many low-level control tasks.

A self-driving car needs a perception system to sense things that are moving (cars, people) as well as things that aren't (lampposts, curbs). Self-driving vehicles detect dynamic objects using sensors such as cameras, laser scanners, and radar. Of these three, cameras are the cheapest, but they're also used the least because it's hard to translate images into detected objects. Using deep learning, we're seeing dramatic improvements in the car's ability to understand and make use of such images.

We're also seeing significant gains from something called “multitask deep learning,” in which a system trained simultaneously to detect lane markings,

cars, and pedestrians does better than three separate systems trained in isolation—since the single network can share information among the separate tasks.

Instead of relying entirely on a pre-computed map, the car can use the map as one of many data streams, combining it with sensor inputs to help it make decisions. (A neural network that knows from map data where crosswalks are, for example, can more accurately detect pedestrians trying to cross than one that relies solely on images.)

Deep learning can also alleviate one of the biggest issues identified by many who have ridden in a self-driving car—a “jerky” feel to the driving style, which sometimes leads to motion sickness. But a car trained using examples of humans driving can offer a ride that feels more natural.

It's still early. But just as deep learning did with image search and voice recognition, it is likely to forever change the course of self-driving cars.

Carol Reiley is the cofounder of Drive.ai.

INFORMATION TECHNOLOGY

Factories 2.0

Manufacturing fell behind the information revolution. That's about to change.

Since 1994, the number of manufacturing jobs in the U.S. has dropped by almost 30 percent. The common explanation has been that domestic factories need fewer workers because they've become much more productive.

But that's all wrong. The problem isn't that we're too productive. The problem is we're still not productive enough (see “Learning to Prosper in a Factory Town,” page 64).

Yes, it's true that since 1994 manufacturing labor productivity has doubled. But if you measure something called “multi-

factor productivity” you get a different story. Multifactor productivity takes into account how efficiently a factory uses *all* its inputs—not just labor but also equipment, buildings, energy, purchased parts and services, software, and research and development. Because it includes a wider scope of inputs and costs, multifactor productivity is a better indicator of how innovative and competitive an industry really is.

Since 1994, multifactor productivity has declined in nine out of 18 domestic manufacturing industries. And if domestic manufacturing can’t become more efficient, it will have a tough time competing in the global economy and an even tougher time adding jobs.

But we’re in luck—there’s a simple way that domestic factories can increase their productivity, expand their market share, and hire more workers. The answer (perhaps surprisingly) is to invest more in information technology.

U.S. manufacturers currently put only 10 percent of their capital spending into tech equipment and software, according to data from the Bureau of Economic Analysis. That’s down from 15 percent in 2000 and 12 percent as recently as 2007. Even if we add robots to the picture, the figures don’t change much. North American purchases of robots amounted to only \$1.6 billion in 2015, or less than 0.3 percent of total investment by manufacturers.

Compare that with the economy as a whole, where computers, peripherals, communications gear, and software make up 22 percent of nonresidential capital spending. Manufacturers fell behind in the information revolution.

In part, that’s a reflection of how much harder it is to digitize the production of a physical object such as a machine than an “information object” such as a newspaper. But recent advances in technology mean manufacturers are finally getting low-cost wireless sensors that can report back on the state of physical processes, computing

systems that can process data in real time, and the algorithms to quickly act on that data to cut costs and improve quality.

Perhaps most important, domestic manufacturers won’t just be producing old products more efficiently; they’ll also be using cutting-edge technology and smart design to create products that were impossible to make before—things like artificial organs and “smart” furniture that adjusts itself to the contours of the people using it. New production capabilities will unleash a flood of creativity that will benefit both consumers and companies.

We’re about to find out that innovation in domestic manufacturing isn’t a job destroyer at all—it’s a job creator.

Michael Mandel is chief economic strategist of the Progressive Policy Institute.

ENERGY

Wind on the Upswing

As it gets ever cheaper, wind energy will play a huge role in our clean-power future.

Last May I attended an international meeting on wind energy in Portugal, where 100 percent of that country’s electricity demand was met by renewable energy—a combination of solar, wind, and hydro—for four days. There have also been several short periods in which wind generation alone has exceeded 40 percent of demand in U.S. regional systems in places like Texas, Oklahoma, Kansas, Nebraska, and Colorado.

Some people think wind has value only in limited locations and will play a small role in meeting our overall energy needs (see “The One and Only Texas Wind Boom,” page 40). Instead, a history of cost reductions combined with decades of deployment and operating experience are bringing wind power to the cusp of transforming our electricity industry.

Yes, there are challenges. Wind is unlikely to ever be our sole source of electricity. Because the wind is variable, it creates some problems for the electric grid, but they’re not insurmountable. My organization has done studies that have looked into what would happen if wind and solar generated a third to a half or more of U.S. annual electricity demand, and we’ve found that there are ways to mitigate this natural variability by using flexible generators, such as natural gas or hydropower plants, and by coordinating operations over large geographic areas. In places like Denmark, Portugal, and Ireland, operators are already successfully managing the variable power generation that comes from wind and solar plants.

Thanks to research and development programs and policy incentives, the cost of wind has dropped by an order of magnitude since the early 1980s. Today there are long-term electricity price agreements in the U.S. supplying utilities with wind power at prices that are lower than operating costs for natural-gas plants, leveraged by technology advancements and favorable tax policy.

A recent survey of 163 industry experts found that the cost of wind energy is likely to drop 24 to 30 percent by 2030. They attribute this to a variety of technology, design, manufacturing, construction, and operational changes. Larger rotors, taller towers, and rotor design advancements should allow land-based wind technology to capture more energy at lower cost. Offshore wind technology will take advantage of larger turbines, better designs for foundations and support structures, and economies of scale through larger project size.

We’ve been waiting for low-carbon technologies to transform the power sector. We may finally be seeing it happen.

Maureen Hand is a senior engineer with the Strategic Energy Analysis Center of the National Renewable Energy Laboratory.

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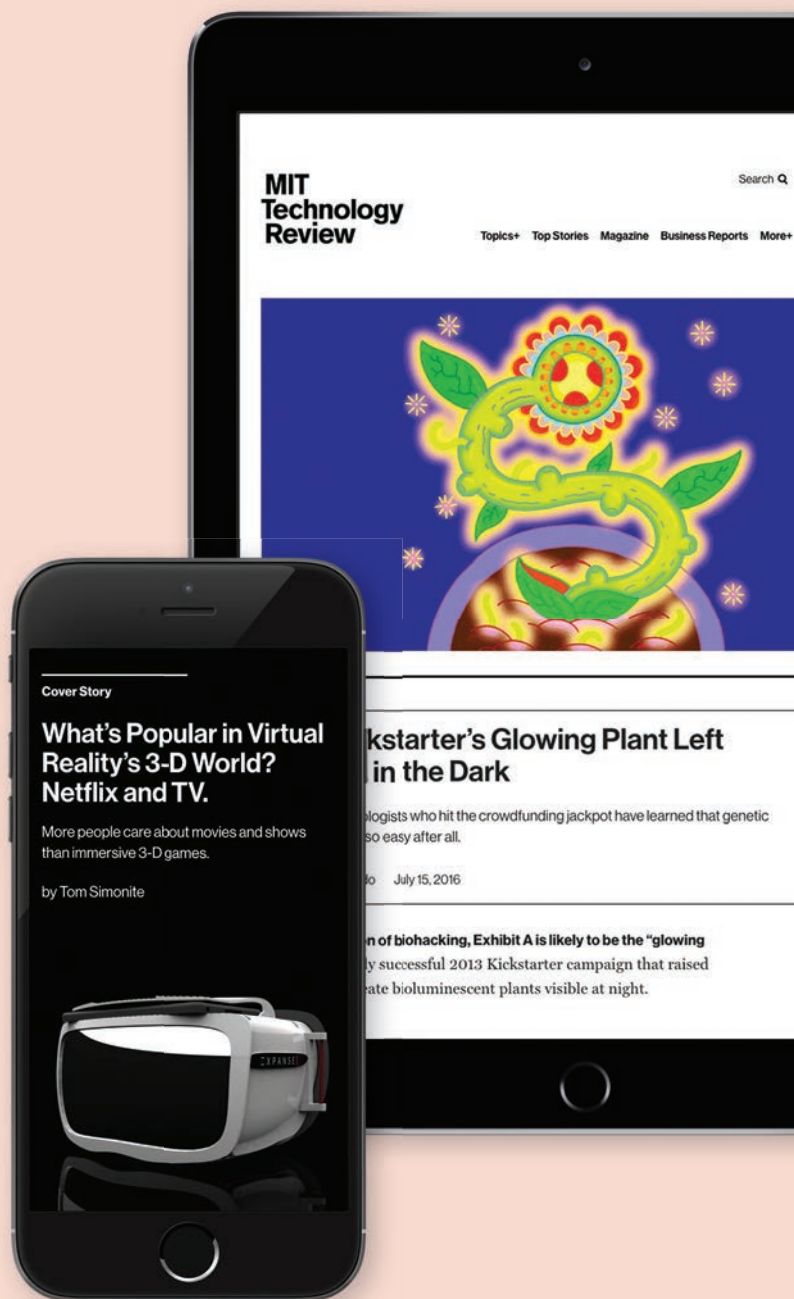
Better Lithium Batteries to Get a Test Flight on Drones

By Richard Martin

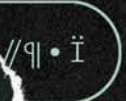
China's Headlong Rush into an Ultra-Expensive Cancer Therapy

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Microsoft's Civil Rights Crusader

Brad Smith is fighting the U.S. government in a series of cases that will shape online privacy—and the cloud business.

MIKE MCCUADE

When Apple CEO Tim Cook refused to help the FBI get into a mass murderer's iPhone last winter, he was hailed for his boldness in fighting the government on a matter of principle. In fact, Cook was borrowing from the playbook of a top executive at Apple's dowdier rival Microsoft—a genial, sandy-haired man named Brad Smith.

Upfront

Smith, 57, has taken the government to court four times in the past three years, each time accusing it of breaching the Constitution in its efforts to get its hands on Microsoft customers' data. He believes computers and the Internet have weakened vital checks on government surveillance that have typically helped to assure personal privacy. Now Smith, Microsoft's president and chief legal officer, says he is waging a legal war on the government in an attempt to restore those checks. "We shouldn't depart from the historic balance," he says, speaking in his bland corner office on Microsoft's quiet campus in Redmond, Washington.

Smith's cases affect anyone who uses the Internet, from large corporations with data in the cloud to the millions of individuals using Skype and Web mail. The smartphones, browsers, and dating apps we have so enthusiastically embraced generate piles of data that can be reviewed by investigators. But restraints on the investigators' power were mostly devised in a world where data was stored on paper. The Fourth Amendment and the laws and court rulings built around it force cops to get a warrant from a judge if they want to tap your phone, read your postal mail, or inspect papers in your home, for example. But while the police need a warrant to search your smartphone, they don't need one to see many digital traces of your life, such as logs of your past movements from a cellular network. Smith says that as Microsoft and other tech companies stand up to the government in court, they can help restore the limits on surveil-

lance powers that their own products have unintentionally weakened. Microsoft won its latest case this summer, when a federal appeals court rejected the Department of Justice's claim that U.S. warrants served on the company could now be used to pull in data held in other countries.

Challenging the government over the scope of search warrants may seem like administrative arcana next to causes that get crowds of protesters onto the streets. But there is a connection between Microsoft's court cases and other civil rights battles, says Neil Richards, a law professor at Washington University in St. Louis. Protest movements can't form, he says, unless people with unconventional ideas can communicate and organize without the government looking over their shoulder. "It's only because of freedom of speech and protection from surveillance

that we have desegregation, or marriage equality, or the trans bathroom fight in the upper South," he says. "We need the breathing space to [protest] in an age of digital surveillance."

Google, Twitter, and other tech companies have also challenged the government over surveillance in recent years, but Smith stands out. Technology executives at his level aren't usually so visible and active on issues of privacy and security, says Ashkan Soltani, a privacy researcher who was until this year chief technologist at the Federal Trade Commission.

Smith joined Microsoft in 1993, and later helped the company resist government antitrust charges. But his focus changed after the Edward Snowden leaks. Smith has memorized the exact

date—October 30, 2013—that the *Washington Post* published what he considers the worst of the secrets revealed by the onetime intelligence agency IT contractor. It described a U.S.-U.K. project called Muscular, which harvested data from the private networks of Google and Yahoo without the companies' knowledge. "It perhaps more than anything else caused a whole industry to step back and ask, 'Hey, what's going on here?'" says Smith. "It caused us to get more engaged in the public discussion."

Trust was a problem for Microsoft and other large Internet companies after the Snowden leaks. Smith says existing and potential customers overseas expressed concern that using Microsoft services would open up their data to the U.S. government. Microsoft and other companies named in the leaks protested that they did not let the government directly access their systems and only handed over data in response to legitimate requests. In an angry letter to Attorney General Eric Holder, Smith warned that the Constitution was "suffering" because government lawyers, citing national security, wouldn't let Microsoft publicly explain the protocols followed for data requests. The company joined Google in a legal action (later joined by Facebook and Yahoo as well) that won them the right to report approximately how many requests they have received from the secret agency that signs off on NSA activity inside the U.S.

That case illustrates Smith's multiple motivations for campaigning on privacy. He believes U.S. law urgently needs updating to protect rights in the Internet age, but he also has a duty to Microsoft's business. The company is betting heavily on cloud computing services. To win and keep customers, particularly among companies overseas, it must be seen as a safe, trustworthy custodian of their data.

—Tom Simonite



Policing Driverless Cars

Christopher Hart, who heads the National Transportation Safety Board, thinks we may never reach full automation on U.S. roads.



Auto accidents kill more than 33,000 Americans each year, and companies working on self-driving cars, such as Alphabet and Ford, say their technology can slash that number by removing human liabilities (see “Your Driverless Ride Is Arriving,” page 34). But Christopher Hart, chairman of the National Transportation Safety Board, says that humans can’t be fully removed from control. He told *MIT Technology Review* that autonomous vehicles will indeed be much safer but will still need humans as copilots.

How optimistic are you that self-driving cars will cut into the auto accident death toll?

I’m very optimistic. For decades we’ve been looking at ways to mitigate injury when you have a crash. We’ve got seat belts, we’ve got air bags, we’ve got more robust [auto body] structures. Right now, we have the opportunity to prevent the crash altogether. And that’s going to save tens of thousands of lives.

Autopilot systems can also create new dangers. The NTSB has said that air pilots’ overreliance on automation has caused crashes. Do you worry about this phenomenon being a problem for cars, too?

The ideal scenario that I talked about, saving the tens of thousands of lives a year, assumes complete automation with no human engagement whatsoever. I’m not confident that we will *ever* reach that point. I don’t see the ideal of complete automation coming anytime soon. Some people just like to drive. Some people don’t trust the automation, so they’re going to want to drive. [And] there’s no software designer in the world that’s ever going to be smart enough to anticipate all the potential circumstances this software is going to encounter.

The challenge is that when you have not-so-complete automation, with still significant human engagement, complacency becomes an issue. That’s when lack of skills becomes the issue. So our chal-

lenge is: how do we handle what is probably going to be a long-term scenario of still some human engagement in this largely automated system?

Some people say that self-driving cars will have to make ethical decisions—for example, deciding whom to harm when a collision is unavoidable. Is this a genuine problem?

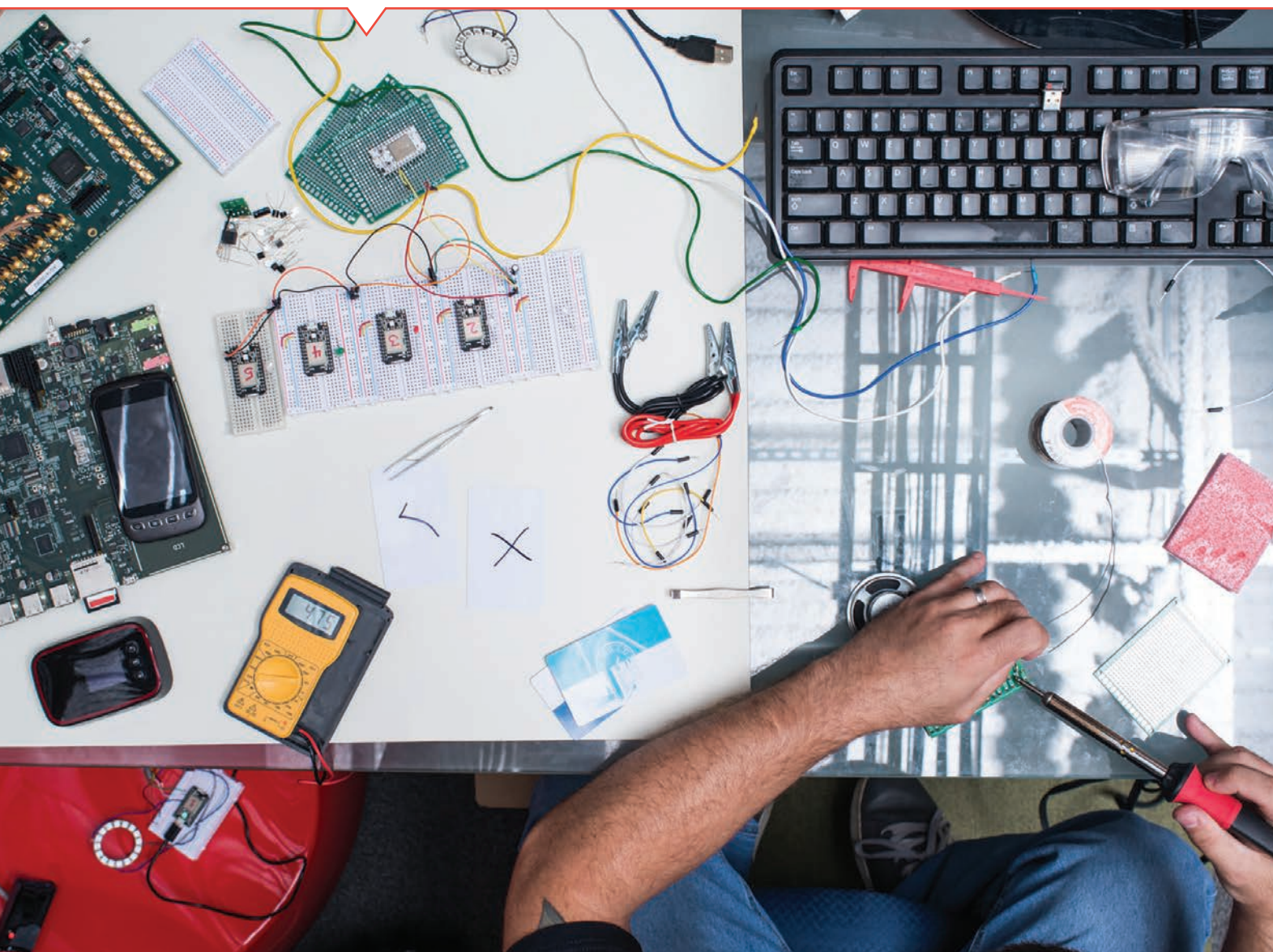
I can give you an example I’ve seen mentioned in several places. My automated car is confronted by an 80,000-pound truck in my lane. Now the car has to decide whether to run into this truck and kill me, the driver, or to go up on the sidewalk and kill 15 pedestrians. That would [have to] be put into the system. Protect occupants or protect other people? That to me is going to take a federal government response to address. Those kinds of ethical choices will be inevitable. In addition to just ethical choices—what if the system fails? Is the system going to fail in a way that minimizes [harm] to the public, other cars, bicyclists? The federal government is going to be involved.

What might that look like?

The Federal Aviation Administration has a scheme whereby if something is more likely than one in a billion to happen you need a fail-safe. Unless you can show that the wing spar failing—the wing coming off—is less than one in a billion, it’s “likely” to happen. Then you need to have an alternate load path [a fallback structure to bear the plane’s weight]. That same process is going to have to occur with cars. I think the government is going to have to say, “You need to show me a less-than-X likelihood of failure, or you need to show me a fail-safe that ensures that this failure won’t kill people.” I think setting the limit is going to be in the federal government domain, not state government. —*Andrew Rosenblum*

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AI's Future Is Not So Scary

Artificial intelligence will transform just about everything, but technologists should stop fretting that it's going to destroy the world like Skynet.

The odds that artificial intelligence will enslave or eliminate humankind within the next decade or so are thankfully slim. At the same time, however, AI looks certain to upend huge aspects of everyday life, from employment and education to transportation and entertainment. So concludes a major report from Stanford University coauthored by more than 20

leaders in the fields of AI, computer science, and robotics. The analysis is significant because public alarm over the impact of AI threatens to shape public policy and corporate decisions.

The report predicts that automated trucks, flying vehicles, and personal robots will be commonplace by 2030, but it cautions that remaining technical obstacles

will limit them to certain niches. It also warns that the social and ethical implications of advances in AI, such as the potential for unemployment in certain areas and likely erosions of privacy driven by new forms of surveillance, will need to be open to discussion and debate.

The study, part of a project intended to last 100 years, is something of a rebuttal to some of the alarmist pronouncements that have been made about AI. "No machines with self-sustaining long-term goals and intent have been developed, nor are they likely to be developed in the near future," the report says.

"I really see this as a coming-of-age moment for the field," says Oren Etzioni, CEO of the Allen Institute for Artificial Intelligence, an independent research institute in Seattle, who is a coauthor of the report. "The extreme positive hype is wrong, and the fear-mongering is not based on any data."

The report identifies the most promising areas for future AI research, and Etzioni says key among these is research on ways for humans and AI systems to collaborate effectively. Stanford's One Hundred Year Study on Artificial Intelligence will report findings every five years. The first report focuses on areas in which AI will have a significant impact including transportation, health care, education, and employment. —*Will Knight*

TO MARKET

Moment

Wristband

COMPANY:
Somatic Labs

PRICE:
\$159

AVAILABILITY:
Early 2017



Our mobile devices communicate with us through sounds and screens, but a new wristband relies instead on touch. The device, called Moment, vibrates to convey information. While phones and smart watches can send an alert by vibrating the entire device, Moment uses four motors to allow for different types of haptic feedback depending on what it is trying to say. Instead of glancing at your phone's screen every time a new GPS direction comes up, imagine having an arrow traced on your wrist. For app, text, and other smartphone notifications, the device can assign different tactile patterns to different contacts.

—*Signe Brewster*

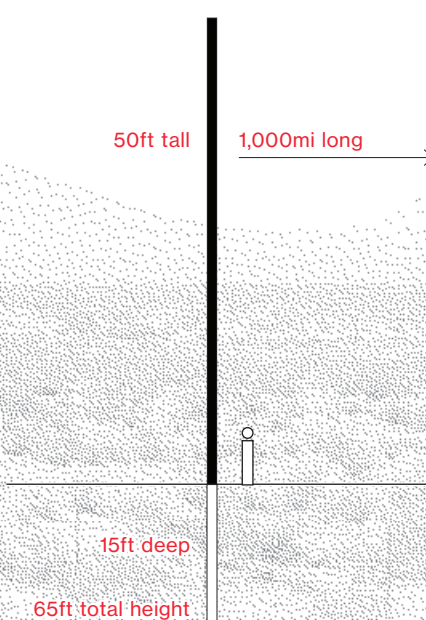
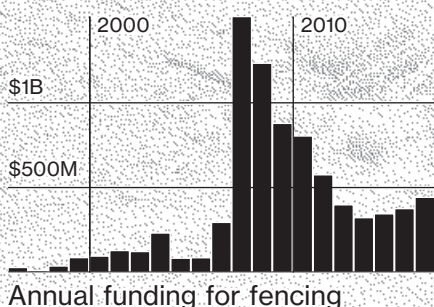
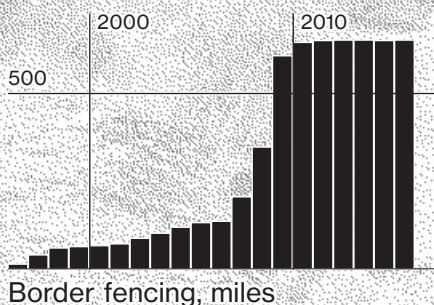
Upfront

Bad Math Props Up Border Wall

Set aside the questions of whether it's wise to put a wall along the U.S.-Mexico border or who should pay for it. It simply can't be done at the price Donald Trump has claimed.

While promising to put up a high concrete wall along the Mexican border, Donald Trump said it would cost between \$8 billion and \$12 billion. Fat chance.

That becomes apparent after you look at what's already on the border. After initially proposing to wall off all 2,000 miles, Trump said the wall could run along roughly half of the border, with mountains and other natural barriers blocking immigrants from crossing elsewhere. And on the portion where Trump envisions a wall, there are already 653 miles of fencing—some designed to stop cars, some to stop pedestrians, depending on the likeliest mode of crossing in each section. Building those fences has cost \$2.3 billion since 2006.



If you wanted a wall instead of a fence—and if it truly were, as Trump has promised, 35 to 65 feet of concrete reinforced with steel—then the costs would mount extremely fast. Imagine a 1,000-mile wall, at a height of about 50 feet, the middle of the range that Trump has thrown out. Then suppose the wall extended 15 feet underground—a little more than is structurally necessary for a foundation, but enough to deter some tunnelers. You wouldn't really build a long wall at a constant thickness, but let's assume that on average, it's one foot thick—enough to make a 50-foot wall stable and hard to cut through, a concern that Trump and his supporters have raised with the existing border fence.

Concrete

This gives you a volume of about 12.7 million cubic yards, or 9.7 million cubic meters. Since structural concrete costs about \$900 per cubic meter, we're talking almost \$9 billion.

$$\begin{aligned} &65 \text{ ft} \times 1 \text{ ft} \times 1,000 \text{ mi} = \\ &\text{height} \quad \text{width} \quad \text{length} \\ &12.7 \text{ million yd}^3 \\ &\text{total volume (9.7 million m}^3\text{)} \\ &\times \$900/\text{m}^3 = \\ &\text{average price} \\ &\$8.7 \text{ billion} \\ &\text{approximate cost of concrete} \end{aligned}$$

DATA FROM CONGRESSIONAL RESEARCH SERVICE, U.S. DEPARTMENT OF HOMELAND SECURITY, GOVERNMENT ACCOUNTABILITY OFFICE, WASHINGTON STATE DEPARTMENT OF TRANSPORTATION, SANDIA NATIONAL LABORATORY, U.S. SENATE COMMITTEE ON HOMELAND SECURITY AND GOVERNMENTAL AFFAIRS, UNITED NATIONS OFFICE FOR COORDINATION OF HUMANITARIAN AFFAIRS

Steel

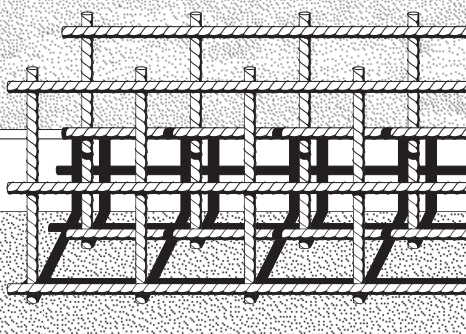
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Labor

=

up to \$40 billion

Steel reinforcement, or rebar, could take up about 3 percent of the volume of the concrete. That amount of rebar would weigh about 2.3 billion kilograms. At roughly \$2 per kilogram, count on spending \$4.6 billion for steel.



$$9.7 \text{ million m}^3 \times .03 \times 7,900 \text{ kg/m}^3 =$$

rebar roughly 3% of the concrete volume, converted to weight (1 m³ of steel=7,900kg)

$$2.3 \text{ billion kg} \times$$

total weight

$$\$2/\text{kg} =$$

average price

\$4.6 billion

approximate cost of steel

If you assumed the same labor costs as what went into putting up the border fences between 2006 and 2009, and added that to the expense of the concrete and steel, the total cost of a wall might be \$15 billion. But the labor for such a project would be much more expensive, especially since the parts of the border that are still open are more rugged.

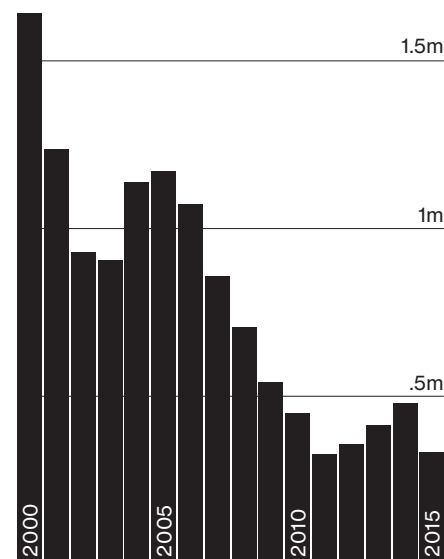
Consider Israel's experience. It has built 320 miles of a planned 480-mile barrier in and around the West Bank. Only three to 10 percent of the completed portion is concrete. The cost so far: \$2.6 billion, more than twice as much per mile as the fences along the U.S.-Mexico border, even though labor in Israel is slightly cheaper.

That fits with what structural engineers have told me: the total cost of highways and other megascale projects in the U.S. is generally two to three times the material costs. That makes a 1,000-mile wall pencil out at \$27 billion to \$40 billion.



Trump might say it would be worth the cost since border crossings are out of control. However, because of several factors, including improvements in the Mexican economy and increases in Border Patrol staffing, fewer people are making the attempt. Officers caught 331,000 people crossing the Mexican border in fiscal 2015, less than one-fifth the number in 2000. —Konstantin Kakaes

Annual arrests of people crossing the U.S.-Mexico border



Upfront

Reinventing Intel

Will faster data storage and chips with built-in lasers help turn Intel around?

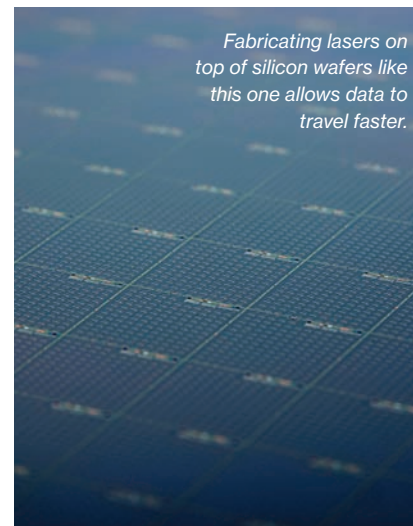
The world's biggest chip maker says it's time to start building computers differently. Intel executives recently showed off two new technologies for storing data and moving it around that could shake up established ways of designing computers. The new technologies are primarily being targeted at the giant data centers that power mobile apps, websites, and emerging ideas in artificial intelligence. They could also appear in consumer products.

Intel needs some new markets. In April the company announced it was laying off 12,000 workers and abandoning making chips for mobile devices, a huge market Intel missed out on. The company has also had to slow the pace at which it brings out new generations of smaller transistors, a trend that has underpinned the industry and Intel's business for decades (see "50 Smartest Companies," July/August 2016).

One of Intel's new technologies is a form of data storage that's faster than the flash disks used in laptops and data centers today. Intel calls it Optane. It is based on technology called 3D Xpoint, developed in collaboration with memory man-

ufacturer Micron. Intel has not disclosed how 3D Xpoint works, but it is believed to write data by heating a glass-like "phase change" material. Intel says it will launch Optane disks in 2016 and memory chips that fit into the same slots as a computer's RAM in 2017. It says an Optane drive can locate and access a piece of data in a tenth the time a flash disk, or SSD, would need.

In the past few years, flash disks have been enthusiastically adopted by computing companies to make servers and consumer PCs snappier. If Optane drives appear in PCs, they should also boost performance. And Ethan Miller, a professor and director of the Center for Research in Storage Systems at the University of California, Santa Cruz, says that Intel and Micron's technology could have an even larger impact than flash on how people build and use computer systems if researchers and companies outside Intel embrace and experiment with it. For instance, Optane memory chips might offer ways to make the expensive data centers that underpin search engines and social networks much more efficient—something Internet giants such as Face-



Fabricating lasers on top of silicon wafers like this one allows data to travel faster.

book would gladly pay for. The chips also retain their data when powered off.

Intel has also developed a faster way to move data between computers. It has begun manufacturing silicon chips with tiny built-in lasers as a way to replace some copper cables inside data centers with fiber-optic ones. Fiber-optic links are today mostly limited to long-range connections, such as telecom networks, because of the size and expense of the components needed. Intel's technology can send 100 gigabits of data per second over a single optical fiber a few millimeters thick. —Tom Simonite

TO MARKET

Expanse

Virtual-reality headset

COMPANY:
Expanse

PRICE:
\$80

AVAILABILITY:
Early 2017



Companies such as Samsung and Facebook's Oculus promote their virtual-reality headsets by highlighting awe-inspiring 3-D experiences for gaming and virtual travel. But one of the most popular activities among early adopters of the technology is less novel: watching 2-D movies and TV. When you slot your smartphone into Expanse's forthcoming headset, you can watch Netflix and Hulu or play conventional 2-D mobile games on what appears to be a big screen. The device can't simulate depth, but it offers significantly higher resolution than VR headsets, because it doesn't need magnifying lenses or a separate display for each eye. —Tom Simonite

WORLDQUANT PARTNERS WITH MIT

A Letter from the CEO of WorldQuant, LLC

WorldQuant is proud to partner with MIT on several initiatives designed to benefit the Institute, its students, and its faculty. WorldQuant is a quantitative investment management firm based in the United States with more than 500 employees in 14 countries. As a leader in the field of quantitative finance with numerous MIT alumni on our executive team, WorldQuant will sponsor several programs associated with the Institute.

IDSS: WorldQuant is a founding industry member of the MIT Institute for Data, Systems, and Society. The IDSS mission of advancing education and research in state-of-the-art, analytical methods in information and decision systems fits perfectly with WorldQuant. Given the importance of high-quality data in the world of quantitative finance, WorldQuant will collaborate with IDSS to provide opportunities for faculty and students to explore and conduct a variety of research projects. This is expected to include projects both related and unrelated to finance.

HUBweek: WorldQuant is a named partner for the Boston area's HUBweek festival, and is proud to have been a participating sponsor of HUBweek 2016, which included events on and around the MIT campus. Because HUBweek celebrates innovation at the



Igor Tulchinsky
CEO, WorldQuant, LLC

intersection of art, science and technology, the event is a natural fit with several of our business initiatives. The HUBweek Inclusive Innovation focus provides the foundation for our Solve-a-thon at MIT, a quantitative-finance contest that allows interested candidates to use web-based technology to build algorithms for stock-price movement prediction. Our current Solve-a-thon at MIT continues through November 30, 2016.

Solve: As a Solve Supporting Organization, WorldQuant embraces the problem-solving program's four pillars — Learn, Cure, Fuel, Make. With the recent establishment by the

WorldQuant Foundation of WorldQuant University, we stand next to MIT in the Learn pillar with a desire to provide high quality education to anyone, anywhere, who has the will to learn. WorldQuant University is a tuition-free online university offering a master of science degree in quantitative finance. We believe that talent is truly global but opportunity is not, and access to education should be available worldwide.

It is with great pride and honor that WorldQuant partners with MIT on these various initiatives. Please visit us at www.WorldQuant.com to learn more about WorldQuant's mission, values, and career opportunities.

Igor Tulchinsky, CEO, WorldQuant, LLC



Solve-a-thon at MIT

Our quantitative finance
contest is underway!

Solve-a-thon at MIT runs
through November 30, 2016

Register at: www.WorldQuantChallenge.com

Upfront

QUOTED

“It’s only a one-time thing, and it’s a chance to improve my life.”

— 17-year-old Gary Ruot, who was admitted into a gene therapy trial to treat his eye disease after circulating a petition to allow patients under 18 into it.

“It can be unsettling, but we’ve tested it in a lot of places and it just works.”

— Quoc Le, a Google researcher, referring to a major upgrade to the company’s language translation system. Based on deep learning, the system often does its work in ways that are mysterious even to the people who created it.

“Maybe by taking out the bogeyman, the public can finally start to entertain scientific conversations about agricultural technology.”

— University of Florida horticulture professor Kevin Folta on Bayer’s takeover of Monsanto.

BY THE NUMBERS

32

Number of states that allow ballots to be cast over the Internet, despite persistent recommendations against it from security experts.

\$999

Amount it costs to make any car semi-autonomous with Comma.ai’s forthcoming off-the-shelf package.

\$200,000

Amount SpaceX CEO Elon Musk thinks it will someday cost an individual to travel to Mars on one of his company’s rocket ships.

Why We Still Don’t Have Better Batteries

Startups with novel chemistries tend to falter before they reach full production.

Despite very promising results from scores of battery research projects, low-cost energy storage remains elusive. A number of startups are closer to producing devices that are economical, safe, compact, and able to store energy at a cost of less than \$100 a kilowatt-hour. Energy storage at that price would have a galvanic effect, overcoming the problem of powering a 24/7 grid with renewable energy that’s available only when the wind blows or the sun shines, and making electric vehicles lighter and less expensive. But those batteries are not being commercialized at anywhere near the pace needed to hasten the shift from fossil fuels to renewables.

In fact, many researchers believe energy storage will require an entirely new chemistry and a new physical form, replacing the lithium-ion batteries that over the last decade have shoved aside competing technologies in consumer electronics, electric vehicles, and grid-scale storage systems. Qichao Hu, the founder of SolidEnergy Systems, has developed a lithium-metal battery that offers dramatically improved energy density over today’s devices. The decade-long process of developing the new system highlighted one of the main hurdles in battery advancement: “In terms of moving from an idea to a product,” says Hu, “it’s hard for batteries, because when you improve one aspect, you compro-

mise other aspects.” Added to this is the fact that energy storage research has a multiplicity problem: there are so many technologies, from foam batteries to flow batteries to exotic chemistries, that no one clear winner is emerging.

And even the best-funded startups are destined to struggle. “It will cost you \$500 million to set up a small manufacturing line and do all the minutiae of research you need to do to make the product,” says Gerd Ceder, a professor of materials science at the University of California, Berkeley, who heads a

research group investigating novel battery chemistries. Automakers, he points out, may test new battery systems for years before making a purchase decision. And even if new battery makers manage to bring novel technologies to market, they face a dangerous period of ramping up production and finding buyers. Both Leyden Energy and A123 Systems developed promising new systems, but both failed as their cash needs climbed and demand failed to meet expectations.

Meanwhile, the big three battery producers, Samsung, LG, and Panasonic, are less interested in new chemistries and radical departures in battery technology than they are in gradual improvements to their existing products. And innovative lithium-ion batteries, first developed in the late 1970s, keep getting better.

—Richard Martin



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**MIT
Technology
Review**

Upfront

Gene-Therapy Cure Has Money-Back Guarantee

The most expensive drugs in history, or medicine's biggest bargains? Gene therapy could be both.

The first gene therapy to be sold in Europe comes with a perk you don't often see in medicine: a money-back guarantee.

The treatment, called Strimvelis, is the first outright cure for a rare disorder to emerge from gene therapy, and its price tag of 594,000 euros (\$665,000) makes it one of the most expensive one-time treatments ever sold by a drug firm. It's also the first genetic fix to come with a warranty.

were cured outright. GSK bought rights to the treatment in 2010 and won approval earlier this year to sell it in Europe, but because of its complexity the company will offer it only in Milan, requiring families to spend weeks there. That means the Italian price will apply to all of Europe, says Pani. GSK declined to comment.

By some measures, Strimvelis's price counts as a bargain. The cost of a bone marrow transplant from another person—

brain illness could reach the market next, and they could be similarly expensive.

The Italian agency is unusual in that it already imposes pay-for-performance rules on some cancer drugs. It maintains 135 patient registries to track how well they work, and Pani says Italy has collected more than 250 million euros in refunds. Patients receiving GSK's gene therapy will also be tracked in a registry, the company confirmed. Experience gained so far suggests that GSK might end up refunding the cost of about one in six treatments. But the big question isn't whether gene therapy costs too much—it's whether companies can make any money at it, especially treating ultra-rare diseases. Only about a dozen children are born with ADA-SCID each year in Europe. Treating all of them would generate about \$8 million—barely a blip for GSK, which sells \$30 billion worth of drugs a year.

"Treating 12 kids a year—it's just not commercially viable, at any price," says Phil Reilly, a partner at Third Rock Ventures in Boston, who invests in gene-therapy companies. "We need a new model for ultra-rare disorders, because we are going to develop these treatments." Reilly says money-back guarantees and pay-as-you-go schemes are two ways to make high sticker prices palatable.

GSK says it won't make much money off Strimvelis. Instead, it sees the treatment as a way to help patients and gain experience with genetic treatments. It's also working with a small company, Adaptimmune, to genetically alter immune cells to battle cancer. "We hope that Strimvelis will be the first of a number of innovative gene-therapy medicines that we will bring to patients," says Anna Padula, a spokesperson for GSK's rare-diseases group. The company recognizes, she adds, "that the industry will need to adapt the way in which medicines are priced and funded." —*Antonio Regalado*



"The drug has to deliver what you say or we don't pay," says Luca Pani, director general of the Italian Medicines Agency, known as AIFA, which set the price and terms during negotiations with GlaxoSmithKline, the company commercializing Strimvelis. The treatment uses a virus to add a missing gene to the bone marrow of children with ADA-SCID, a sometimes fatal inability to fight infections. In a study involving 18 children, carried out at a Milan hospital, all but three

the established way to treat ADA-SCID—can reach \$1 million. Some other patients get treated with enzyme injections that cost \$250,000 a year. The expense of these drugs and the care needed for a sick child quickly add up to millions.

The idea behind gene therapy is that a one-time correction to a patient's DNA will lead to a lifelong cure. Strimvelis is the first treatment to be commercialized that lives up to the promise. But potential cures for hemophilia, a rare eye disease, and a fatal

Our Ultimate Holiday Wish List

This year's 13 most covetable gadgets, from a wearable that does it all to a virtual-reality gaming kit.

By Sarah Silbert
Illustrations by Miguel Porlan

02

TURN HERE FOR MORE STUFF →

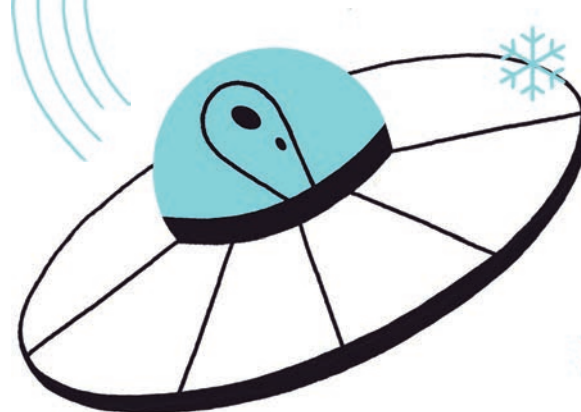
01

FOR THE AERIAL PHOTOGRAPHER

DJI Phantom 4 Drone

\$1,199

Dodge drone crashes with the Phantom 4 from DJI, which includes a collision avoidance system that uses two forward-facing sensors to detect obstacles as far as 49 feet ahead. When the drone detects an object in its path, it will go around it or pause and hover. The quadcopter also features the Tap Fly functionality: if the human pilot taps on a specific object via the smartphone app, the drone will fly toward it.





06

03

FOR THE 8-BIT ENTHUSIAST

Nintendo NES Classic Edition

\$60

Give the gift of nostalgia with this modernized mini version of the original cartridge-based Nintendo Entertainment System console. It maintains the original's retro looks (even for the included controller) and comes with 30 8-bit favorites such as Super Mario Bros., Donkey Kong, and the Legend of Zelda preinstalled. Hook it up to a TV via the bundled HDMI cable, buy an extra controller for \$10, and your post-holiday-dinner entertainment is squared away.

For athletes who like to venture off the beaten path.



02

FOR THE ACTIVE AND OUTDOORSY

Garmin Fenix 3 Sapphire

\$600 and up

The Fenix 3 Sapphire combines Garmin's sports-watch know-how with smart-watch-style notifications. Thanks to GPS and satellite navigation plus tracking features, it's best suited to athletes who venture off the beaten path, but advanced metrics for things like stride length, vertical oscillation, and oxygen intake should come in handy for serious runners everywhere. When connected to a compatible smartphone over Bluetooth, it will also display e-mails, texts, and other alerts directly on the sunlight-readable watch face.



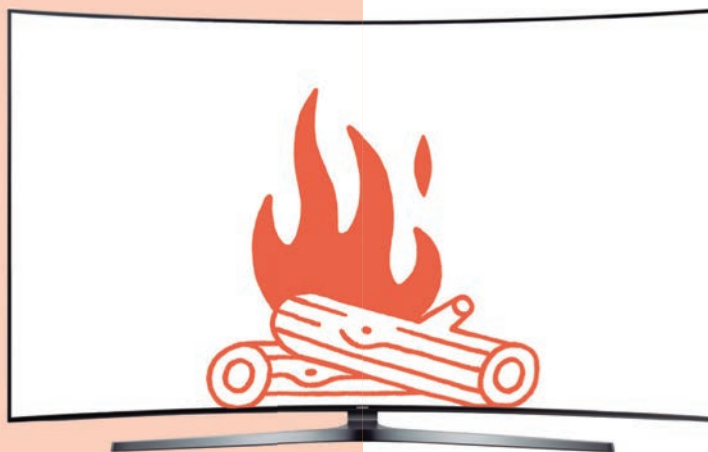
06

FOR THE DOTING PARENT

Withings Thermo

\$100

This smart thermometer proves that stocking stuffers don't have to be useless. The compact gadget uses 16 infrared sensors to take heat measurements and find the hottest point when it's swept across someone's forehead. Since using the Thermo doesn't require contact with the skin, it's more sanitary than alternative temperature-taking methods, but you're not sacrificing accuracy. The Thermo makes it easy to interpret results with a color-coded LED indicator, and the companion smartphone app provides advice based on age, fever level, fever history, and symptoms.



07

FOR THE HOME THEATER JUNKIE

Samsung 4K SUHD Television

\$1,800 and up

If you're shopping for someone with a serious living-room setup, one of Samsung's 4K SUHD TVs could prove to be perfect. Thanks to quantum-dot display technology, which uses tiny particles that emit light in various colors, these sets provide punchier, more saturated color than typical LCD TVs, which



produce cooler, more bluish hues. Plus, it will set you back significantly less than an OLED model. In addition to high-quality images, the flat-panel or curved displays feature built-in Wi-Fi and Samsung's Smart Hub for accessing apps, various streaming services, and live TV.

08

FOR THE EARLY ADOPTER

Lenovo Phab 2 Pro

\$499

For someone who wants the absolute cutting edge in mobile tech, Lenovo's super-sized Android handset is the obvious pick. The Phab 2 Pro is the first smartphone to support Google's augmented-reality Tango platform, which lets you view 3-D software overlays based on what's captured by the device's wide-angle camera and depth sensor—essentially providing a unique way to interact with your environment. For example, an app from the Lowe's home improvement chain lets a user see how an appliance would look in his or her home, moving the items around at the tap of a finger. While Tango is the standout feature, the phone also features a spacious 6.4-inch display and a fingerprint scanner.



09

FOR THE ROBOTICS NUT

Anki Cozmo

\$180

Cozmo is much more than a robotic toy for kids. Thanks to facial-recognition technology, the bot will graduate from shy to friendly with its owners, and it's programmed to remember specifics like your favorite game. When you play games with Cozmo using the included smart blocks, it will react appropriately, even showing disappointment when it loses. Plus, Anki's making the robot's software available to everyone, so you can try your hand at creating additional ways for the toy to interact with its environment.

10

FOR THE COMMUTER ON TWO WHEELS

Stromer ST2

\$6,990 and up

Reward your favorite eco-conscious commuter with this souped-up, connected e-bike. The ST2'S battery lasts for up to 93 miles per charge, and riders can enjoy motor-boosted speeds of up to 27 miles per hour. In addition to toggling settings via buttons on the handlebar, the rider can tweak them in the Stromer smartphone app for Android and iOS (not advised while riding!). The ST2 looks decidedly high-end, so you'll want to ensure it stays safe. To that end, it comes with several antitheft features: you can lock and unlock it remotely, and when it's locked it will remain immobilized. Plus, if someone does try to haul it off, the owner will receive distress texts complete with GPS tracking information.



11

FOR THE SERIOUS GAMER

PlayStation VR

\$399

This head-mounted display system makes playing games like Batman Arkham VR and Star Wars Battlefront more immersive than ever. It connects to a PlayStation 4 via USB and HDMI cables and lets the wearer explore the game environment with a 100° field of view. The PlayStation Camera, sold separately, also connects to the console and tracks the headset's movements. Keep in mind that you'll need this camera, along with a PS4 console, to enjoy virtual-reality gaming with this headset, and most games use a DualShock 4 Wireless Controller.



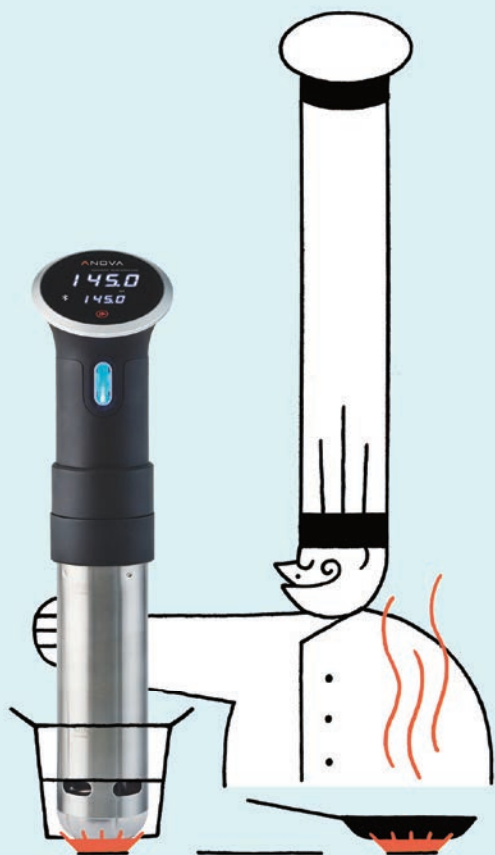
12

FOR THE SERIOUS CHEF

Anova Precision Cooker

\$179

Boil-in-a-bag has gone high tech. The Anova Precision Cooker attaches to the side of any old kitchen pot to heat water and circulate it evenly, allowing for perfectly moist, tender meals prepared in the sous vide style (as long as food is sealed in an airtight plastic bag). Thanks to Bluetooth connectivity and a companion app for Android and iPhone, chefs can start cooking and monitor water temperature from another room. For \$20 more, you can spring for the Wi-Fi-enabled model, which connects to a home network so it can be controlled from afar.



Stuck in traffic after work? No worries. Never burn dinner again.



A camera for the VR filmmaking novice in all of us.

13

FOR THE SOCIAL-MEDIA FIEND

Samsung Gear 360

\$350

The Gear 360 merges images taken with two 180° wide-angle lenses to create 360° shots and videos. Photographers can hit record on the orb-shaped Gear 360 itself or use the smartphone app on a compatible Samsung Galaxy phone to adjust white balance, exposure, and more before capturing images. The best part is viewing the footage: friends and family can pan around 360° videos uploaded to Facebook, YouTube, or the Google Street View app. If you're feeling extra generous, you could also add a head-mounted Samsung Gear VR so the giftee has a more immersive way to take in 360° content.



04

FOR THE ROAD-TRIPPER

Happier Camper HC1

\$16,950 and up

This retro-style trailer weighs just 1,100 pounds, so your favorite camper or Airstream aficionado can tow it with most cars for camping trips and cross-country adventures. The HC1 features a modular interior that can be arranged into various modes, from a sleeping space for five to a mobile office to a living space with a kitchenette. The base model comes with two AC wall plugs, dimmable switch lighting, and seven storage shelves, among other features, and you can shell out for extras such as a stove top, an air conditioner, a 100-watt solar panel with a charger and inverter, and a solar-heated shower.



05

FOR THE DISCERNING AUDIOPHILE

Astell & Kern AK70

\$599

While most of the world has moved on to streaming services such as Spotify, those who value high-resolution playback still cling to portable music players, and the high-end South Korean brand Astell & Kern is still improving them. The Android-based, Wi-Fi-compatible AK70 supports hi-res files like AIFF, FLAC, and WAV, in a reasonably light (4.7-ounce) package. You can control volume with either the hardware button or the player's 3.3-inch LCD touch screen.



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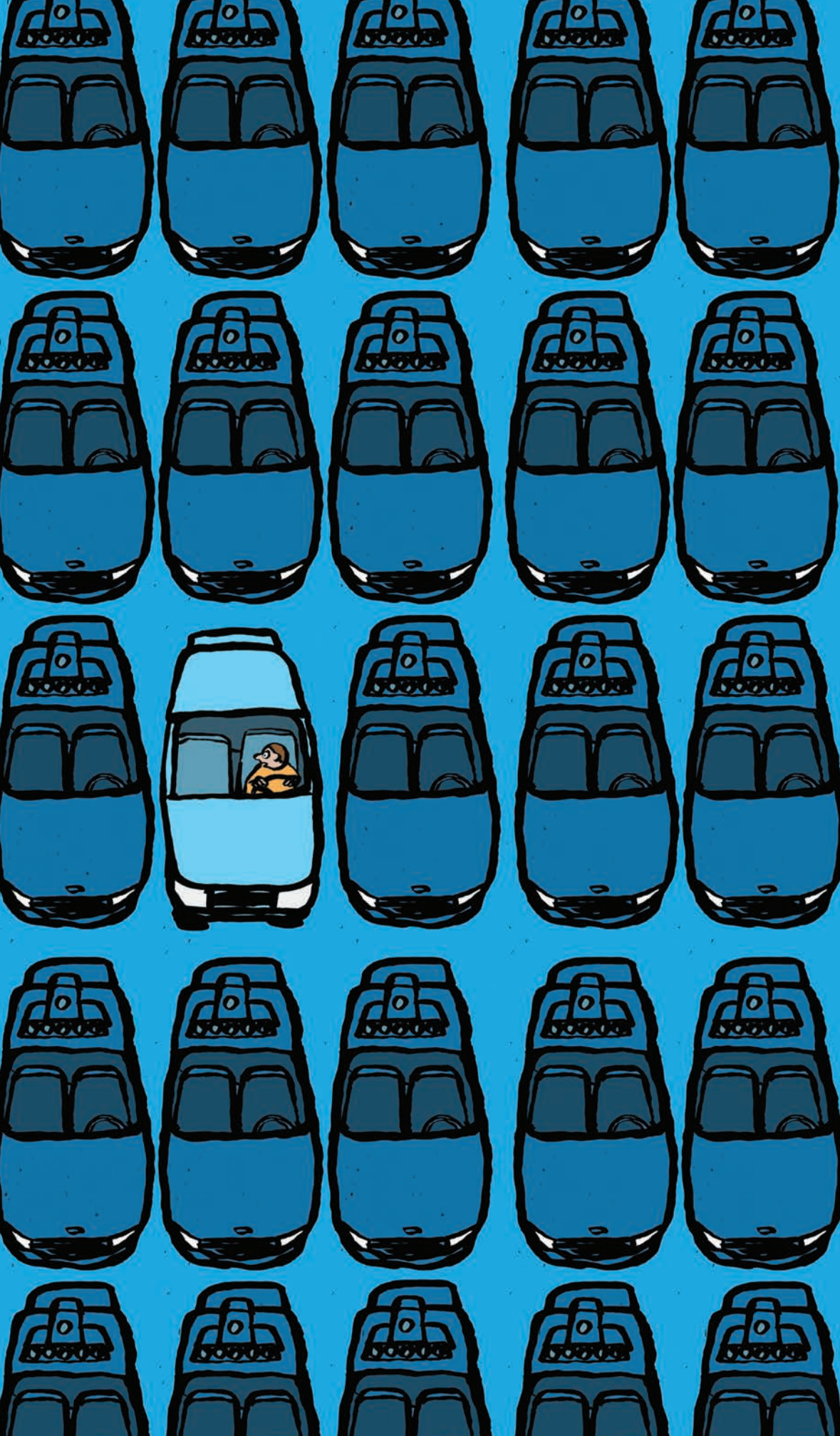
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Artificial Intelligence).*





**Your Driverless
Ride Is Arriving**

Uber thinks its self-driving taxis could change the way millions of people get around. But autonomous vehicles aren't anywhere near to being ready for the roads.

By Will Knight

Illustration by
Jean Jullien



outside a large warehouse in Pittsburgh, in an area along the Allegheny River that was once home to dozens of fac-

tories and foundries but now has shops and restaurants, I'm waiting for a different kind of technological revolution to arrive. I check my phone, look up, and notice it's already here. A white Ford Fusion, its roof bedazzled with futuristic-looking sensors, is idling nearby. Two people sit up front—one monitoring a computer, the other behind the wheel—but the car is in control. I hop in, press a button on a touch screen, and sit back as the self-driving Uber takes me for a ride.

As we zip out onto the road toward downtown, the car stays neatly in its lane, threading deftly between an oncoming car and parked trucks that stick out into the street. I've been in a self-driving car before, but it's still eerie to watch from the back seat as the steering wheel and pedals move themselves in response to events unfolding on the road around us.

To date, most automated vehicles have been tested on highways in places like California, Nevada, and Texas. Pittsburgh, in contrast, features crooked roads, countless bridges, confusing intersections, and more than its fair share of snow, sleet, and rain. As one Uber executive said, if self-driving cars can handle Pittsburgh, then they should work anywhere. As if to test this theory, as we turn onto a bustling market street, two pedestrians dart onto the road ahead. The car comes to a gentle stop some distance from them, waiting and then continuing on its way.

A screen in front of the back seat shows the car's peculiar view of the world: our surroundings rendered in vivid colors and jagged edges. The picture is the product of some of an amazing array of instru-

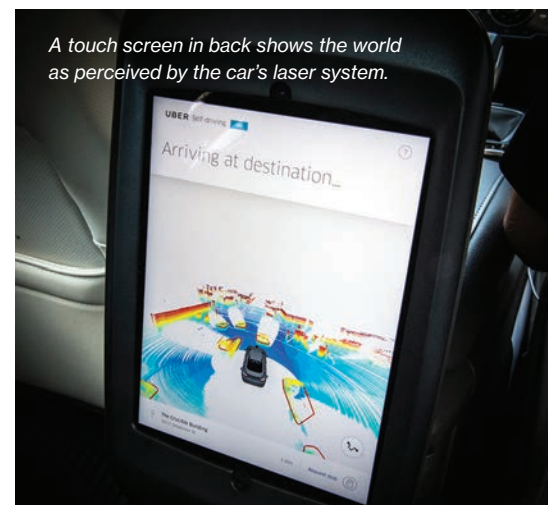
ments arranged all over the vehicle. There are no fewer than seven lasers, including a large spinning lidar unit on the roof; 20 cameras; a high-precision GPS; and a handful of ultrasound sensors. On the screen inside the car, the road looks aqua blue, buildings and other vehicles are red, yellow, and green, and nearby pedestrians are highlighted with what look like little lassos. The screen also indicates how the vehicle is steering and braking, and there's a button that'll ask the car to stop the ride any time you want. This being 2016, Uber has even made it possible for riders to take a selfie from the back seat. Shortly after my ride is over, I receive by e-mail a looping GIF that shows the car's view of the world and my face grinning in the top-right corner. People on the sidewalk stop and wave while we wait at a traffic light, and a guy driving a pickup behind us keeps giving the thumbs-up.

My ride is part of the highest-profile test of self-driving vehicles to date, after Uber began letting handpicked customers book rides around Pittsburgh in a fleet of automated taxis. The company, which has already upended the taxi industry with a smartphone app that lets you summon a car, aims to make a significant portion of its fleet self-driving within a matter of years. It's a bold bet that the technology is ready to transform the way millions of people get around. But in some ways, it is a bet that Uber has to make. In the first half of this year it lost a staggering \$1.27 billion, mostly because of payments to drivers. Autonomous cars offer "a great opportunity for Uber," says David Keith, an assistant professor at MIT who studies innovation in the automotive industry, "but there's also a threat that someone else beats them to market."

Most carmakers, notably Tesla Motors, Audi, Mercedes-Benz, Volvo, and General Motors, and even a few big tech companies including Google and (reportedly) Apple, are testing self-driving vehicles.

Tesla cars drive themselves under many circumstances (although the company warns drivers to use the system only on highways and asks them to pay attention and keep their hands on the steering wheel). But despite its formidable competition, Uber might have the best opportunity to commercialize the technology quickly. Unlike Ford or GM, it can limit automation to the routes it thinks driverless cars can handle at first. And in contrast to Google or Apple, it already has a vast network of taxis that it can make gradually more automated over time.

Uber's executives have little trouble imagining the upside. With no drivers to split revenues with, Uber could turn a profit. Robot taxis could become so cheap and easy to use that it would make little sense for anyone to actually own a car. Taken to its logical conclusion, automated driving could reprogram transportation itself. Uber is already experimenting with food delivery in some cities, and it recently bought Otto, a startup that is developing automated systems for long-haul trucks. Self-driving trucks and vans could ferry goods from fulfillment centers and stores to homes and offices with dizzying speed



and efficiency. Shortly before my test ride Andrew Lewandowski, head of Uber's autonomous operations, a veteran of Google's self-driving program, and one of the cofounders of Otto, said: "I really believe that this is the most important thing computers are going to do in the next 10 years."

Uber is moving quickly. The company created its Advanced Technology Center, where it's developing its driverless cars, in February 2015 by hiring a number of researchers from the robotics department at nearby Carnegie Mellon University. Using that expertise, Uber developed its self-driving taxis in a little over a year—roughly the amount of time it takes most automakers to redesign an entertainment console.

But is it moving too quickly? Is the technology ready?

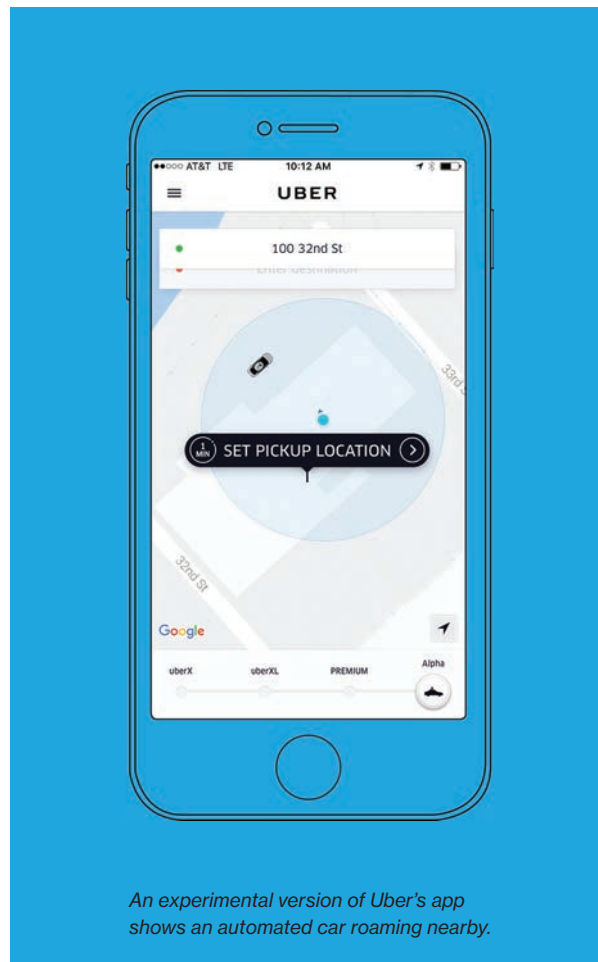
Robo ancestors

For the rest of my time in Pittsburgh, I get around using Ubers controlled exclusively by humans. The contrast is stark. I want to visit CMU's National Robotics Engineering Center (NREC)—part of its Robotics Institute, one of the pioneering research groups involved in developing self-driving vehicles—to see what its experts think of Uber's experiment. So I catch a ride with a guy named Brian, who drives a beat-up Hyundai Sonata. Brian says he's seen several automated Ubers around town, but he can't imagine a ride in them being as good as one with him. Brian then takes a wrong turn and gets completely

lost. To be fair, though, he weaves through traffic just as well as a self-driving car. Also, when the map on his phone leads us to a bridge that's closed for repairs, he simply asks a couple of road workers for directions and then improvises a new

one to help put your suitcase in the trunk or return a lost iPhone.

I take a rain check on the beer, say good-bye to Brian, and arrive at NREC's vast warehouse about 20 minutes late. The building is filled with fascinating robotic prototypes. And if you look carefully, you'll find some ancestors of today's automated vehicles. Just inside the entrance, for instance, is Terregator, a six-wheeled robot about the size of a refrigerator, with a ring of sensors on top. In 1984, Terregator was among the first robots designed to roam outside of a lab, rolling around CMU's campus at a few miles per hour. And Terregator was succeeded, in 1986, by a heavily modified van called NavLab, one of the first fully computer-controlled vehicles on the road. Just outside the front door to NREC sits another notable forerunner: a customized Chevy Tahoe filled with computers and decorated with what looks suspiciously like an early version of the sensor stack on top of one of Uber's self-driving cars. In 2007 this robot, called Boss, won an urban driving contest organized by the U.S. Defense Advanced Research Projects Agency. It was a big moment for automated vehicles, proving that they could navigate ordinary



An experimental version of Uber's app shows an automated car roaming nearby.

route. He's friendly, too, offering to waive the fare and buy me a beer to make up for the inconvenience. It makes you realize that automated Ubers will offer a very different experience. Fewer wrong turns and overbearing drivers, yes, but also no

traffic, and just a few years later Google was testing self-driving cars on real roads.

The three of these CMU robots show how gradual the progress toward self-driving vehicles was until recently. The hardware and software improved, but

the system struggled to make sense of the world a driver sees, in all its rich complexity and weirdness. At NREC, I meet William “Red” Whittaker, a CMU professor who led the development of Terregator, the first version of NavLab, and Boss. Whittaker says Uber’s new service doesn’t mean the technology is perfected. “Of course it isn’t solved,” he says. “The kinds of things that aren’t solved are the edge cases.”

And there are plenty of edge cases to contend with, including sensors being blinded or impaired by bad weather, bright sunlight, or obstructions. Then there are the inevitable software and hardware failures. But more important, the edge cases involve dealing with the unknown. You can’t program a car for every imaginable situation, so at some stage, you have to trust that it will cope with just about anything that’s thrown at it, using whatever intelligence it has. And it’s hard to be confident about that, especially when even the smallest misunderstanding, like mistaking a paper bag for a large rock, could lead a car to do something unnecessarily dangerous.

Progress has undoubtedly picked up in recent years. In particular, advances

in computer vision and machine learning have made it possible for automated vehicles to do more with video footage. If you feed enough examples into one of these systems, it can do more than spot an obstacle—it can identify it with impressive accuracy as a pedestrian, a cyclist, or an errant goose.

Still, the edge cases matter. The director of NREC is Herman Herman, a roboticist who grew up in Indonesia, studied at CMU, and has developed automated vehicles for defense, mining, and agriculture. He believes self-driving cars will arrive, but he raises a few practical concerns about Uber’s plan. “When your Web browser or your computer crashes, it’s

annoying but it’s not a big deal,” he says. “If you have six lanes of highway, there is an autonomous car driving in the middle, and the car decides to make a left turn—well, you can imagine what happens next. It just takes one erroneous command to the steering wheel.”

Another problem Herman foresees is scaling the technology up. It’s all very well having a few driverless cars on the road, but what about dozens, or hundreds? The laser scanners found on Uber’s cars might interfere with one another, he says, and if those vehicles were connected to the cloud, that would require an insane amount of bandwidth. Even something as simple as dirt on a sensor could pose a problem, he says. “The most serious issue of all—and this is a growing area of research for us—is how you verify, how you test an autonomous system to make sure they’re safe,” says Herman.

Learning to drive

For a more hands-on perspective, I head across town to talk to people actually developing self-driving cars. I visit Raj Rajkumar, a member of CMU’s robotics faculty who runs a lab funded by GM. In the fast-moving world of research into driverless cars, which is often dominated by people in Silicon Valley, Rajkumar might seem a bit old school. Wearing a gray suit, he greets me at his office and then leads me to a basement garage

“We are cognitive, sentient beings. We comprehend, we reason, and we take action. When you have automated vehicles, they are just programmed to do certain things for certain scenarios.”





Uber's vehicles are festooned with different kinds of sensors.

where he's been working on a prototype Cadillac. The car contains numerous sensors, similar to the ones found on Uber's cars, but they are all miniaturized and hidden away so that it looks completely normal. Rajkumar is proud of his progress on making driverless cars practical, but he warns me that Uber's taxis might be raising hopes unreasonably high. "It's going to take a long time before you can take the driver out of the equation," he says. "I think people should mute their expectations."

Besides the reliability of a car's software, Rajkumar worries that a driverless vehicle could be hacked. "We know about the terror attack in Nice, where the terrorist driver was mowing down hundreds of people. Imagine there's no driver in the vehicle," he says. Uber says it takes this issue seriously; it recently added two prominent experts on automotive computer security to its team. Rajkumar

also warns that fundamental progress is needed to get computers to interpret the real world more intelligently. "We as humans understand the situation," he says. "We are cognitive, sentient beings. We comprehend, we reason, and we take action. When you have automated vehicles, they are just programmed to do certain things for certain scenarios."

In other words, the colorful picture I saw in the back of my automated Uber represents a simplistic and alien way of understanding the world. It shows where objects are, sometimes with centimeter precision, but there's no understanding what those things really are or what they might do. This is more important than it might sound. An obvious example is how people react when they see a toy sitting in the road and conclude that a child might not be far away. "The additional trickiness is that Uber makes most of its money in urban and suburban locations," Rajkumar

says. "That's where unexpected situations tend to arrive more often."

What's more, anything that goes wrong with Uber's experimental taxi service could have ramifications for the entire industry. The first fatal crash involving an automated driving system, when a Tesla in Autopilot mode failed to spot a large truck on a Florida highway this spring, has already raised safety questions. Hastily deploying any technology—even one meant to make the roads safer—might easily trigger a backlash. "While Uber has done a great job of promoting this as a breakthrough, it's still quite a way away, realistically," says MIT's Keith. "Novel technologies depend on positive word of mouth to build consumer acceptance, but the opposite can happen as well. If there are terrible car crashes attributed to this technology, and regulators crack down, then certainly that would moderate people's enthusiasm."

I get to experience the reality of the technology's limits firsthand, about halfway through my ride in Uber's car, shortly after I'm invited to sit in the driver's seat. I push a button to activate the automated driving system, and I'm told I can disengage it at any time by moving the steering wheel, touching a pedal, or hitting another big red button. The car seems to be driving perfectly, just as before, but I can't help noticing how nervous the engineer next to me now is. And then, as we're sitting in traffic on a bridge, with cars approaching in the other direction, the car begins slowly turning the steering wheel to the left and edging out into the oncoming lane. "Grab the wheel," the engineer shouts.

Maybe it's a bug, or perhaps the car's sensors are confused by the wide-open spaces on either side of the bridge. Whatever the case, I quickly do as he says. ■

Will Knight is senior editor for AI and robotics at MIT Technology Review. His feature "AI's Language Problem" appeared in the September/October issue.



**THE ONE AND ONLY
TEXAS WIND**

A man in a plaid shirt and blue jeans is walking away from the camera on a dirt path through a dry, grassy field. In the background, a long line of white wind turbines stretches across the horizon under a blue sky with scattered white clouds.

WIND BOOM

Wind power has transformed the heart of fossil-fuel country. Can the rest of the United States follow suit?

By Richard Martin

Photographs by Sandy Carson

Previous pages: Russ
Petty on his land.

Right: A turbine at the
Horse Hollow wind farm.

Rolan Petty stabbed at the dirt with a boot toe and looked up at the broiling west Texas sun. “I call it farming on faith,” he said of his unirrigated cotton farm. “You just have faith that the rain is gonna come.”

If it doesn’t come, Petty has a backup income stream: leasing fees. All around us, towering 150 feet over Petty’s combine and the scrubby-looking cotton plants in neat rows, stood a forest of wind turbines that stretched to the horizon. Petty’s land on the arid plain of west Texas lies on the edge of the vast Horse Hollow wind farm, with 430 turbines spread over 73 square miles. It was the largest wind farm in the world when it was completed, in 2006. Petty’s family leases land to Horse Hollow and another wind farm in the area, making about \$7,500 a year on each of the several dozen turbines on their property. Wind power has become a big windfall for the Pettys, as it has for many landowners in Texas—allowing Rolan and his parents and three brothers to make hundreds of thousands of dollars every year whether the rains come or not. And the Petty farm is just a small player in the largest renewable-energy boom the United States has ever seen.

With nearly 18,000 megawatts of capacity, Texas, if it were a country, would be the sixth-largest generator of wind power in the world, right behind Spain. Now Texas is preparing to add several thousand megawatts more—roughly equal to the wind capacity that can be found in all of California. Most of these turbines are in west Texas, one of the most desolate and windy regions in the continental United States. Fifteen years ago, when

the groundwork for this boom was being set, this area had little but cotton and grain farms, oil fields, scrub and dry riverbeds, and small towns that were mostly withering.

Today it’s a land of spindly white turbines that line the highways—and the pockets of landowners. At night, when the wind blows strongest and steadiest, if you stand out in one of the fields you can hear the great blades make a ghostly *shoop-shoop* sound as they turn. Wind power has brought prosperity to towns that were literally drying up less than a generation ago. “In the 2011 drought a lot of people around here would have filed for bankruptcy if not for the turbines,” said Russ Petty, one of Rolan’s brothers, who was giving me a driving tour of the property. “What it’s done is helped keep this land in the family.”

It has also shown that a big state can get a substantial amount of its power from renewable sources without significant disruptions, given the right policies and the right infrastructure investments. The U.S. Department of Energy’s 2015 report “Wind Vision” set a goal of getting 35 percent of all electricity in the country from wind in 2050, up from 4.5 percent today. In Texas, at times, that number has already been exceeded: on several windy days last winter, wind power briefly supplied more than 40 percent of the state’s electricity. For wind power advocates, Texas is a model for the rest of the country.

But it also reveals what wind power can’t achieve. Overall, wind still represents less than 20 percent of the state’s generation capacity—a number that dips into the low single digits on calm, hot summer days. And even with the wind power boom, the state’s total estimated carbon emissions were the highest in the nation in 2013, the most recent year for which data is available—up 5 percent from the previous year.





An abandoned gas station blown over by strong desert winds, just north of the Mexican border.



What's more, the conditions that have spurred Texas's boom may not be easily duplicated. Not only is Texas scoured by usually steady winds, but it has something most other places lack: a gigantic transmission system that was built to bring electricity from the desolate western and northern parts of the state to the big cities of the south and east, including Dallas, Austin, San Antonio, and Houston. Under a program known as Competitive Renewable Energy Zones, or CREZ, the power lines were approved in 2007 and cost nearly \$7 billion to build. They have added a few dollars a month to residential electricity bills, but they now look like a far-sighted infrastructure investment that other states are unwilling or unable to make.

I drove nearly 1,200 miles, from Abilene to Amarillo and many places in between, this summer to explore the wind explosion in Texas. I wanted to understand what was driving this ongoing boom, and what the ultimate limit might be. How much wind power can the Texas grid absorb, economically and physically? And can other states, and other nations, achieve what Texas has, or are there conditions here that will be difficult or impossible to reproduce anywhere else?

PROSPECTING

Guy Payne is one of the beneficiaries of the wind boom. A former prison guard, he was driving a chain bus—used to transport shackled prisoners—when “I started passing all these wind turbines,” he recalls. In 2003, a friend who'd left the corrections business mentioned the opportunities available in wind energy: free training, good pay and benefits, outdoor work, and a much lower chance of being assaulted by a convict. After a six-month training program with General Electric in Tehachapi, California, Payne became a wind turbine technician, a job that combines many functions: electrician, mechanic, tower climber, emergency first responder. He now oversees 65 technicians for a wind developer, Invenergy, working at multiple farms. One of them, with 100 General Electric turbines, sits in cotton fields east of Lubbock, on the edge of what locals call the Caprock and geographers call the *Llano Estacado*. This vast mesa, which covers much of north-west Texas and eastern New Mexico, has some of the best, most consistent wind on the North American continent—often well above the 28 miles per hour that's ideal for generating electricity.

The day I visited, Payne was getting ready to bring Invenergy's latest Texas farm online. A 257-megawatt complex that will cover 66 square miles of cotton fields and scrub, the Wake Wind Energy Center illustrates how quickly such farms can sprout: ground was broken in January, and the turbines were on track to be at full power production by October.

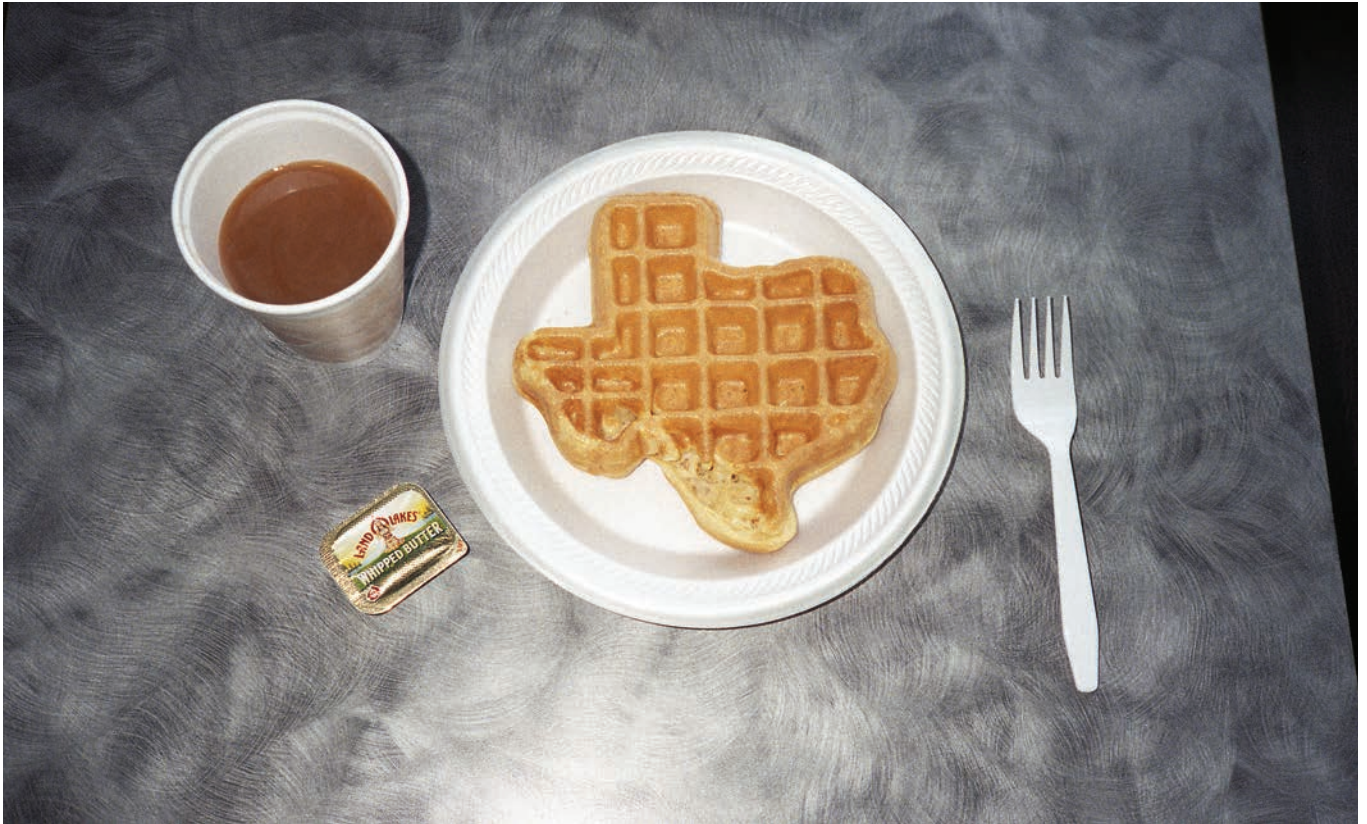
Named for a small ghost town that today is marked only by an antique cotton gin, Wake incorporates state-of-the-art technology: 260-foot towers with rotors 330 feet in diameter, and advanced software that allows technicians to troubleshoot the turbines using laptops. Rapid improvements in technology have made turbines so much cheaper to build and easier to maintain that wind power almost competes with electricity from natural gas on price alone. (Wind power operators are subsidized by federal tax credits and by the long-distance transmission lines that were built at ratepayer expense.)

Wake is distinctive in another way as well: most of the electricity produced here will go directly to two companies, fiber-glass giant Owens Corning and Equinix, which operates big data centers in Dallas. In fact, a growing number of wind farms in Texas are funded by corporations that want to lock in a price for power over 20 years. Facebook, for example, said last year that it will partner on construction of a 200-megawatt wind farm near its new \$1 billion data center in Fort Worth, allowing it to claim that the facility (which will get its power from the regular Texas grid) “will be powered by 100 percent renewable energy.” And Google, which has already invested \$75 million in a wind farm near Amarillo, plans to partner with Invenergy on a new 225-megawatt facility north of Lubbock.

One reason all this is happening is that Texas deregulated its electricity market in 2002, forcing power generators, transmission providers, and electricity retailers to separate. Unlike deregulation in California, which led to a near-collapse of the grid and a series of major blackouts in 2000 and 2001, the policy in Texas has mostly worked as planned, thanks to efficient grid operations and the abundance of transmission lines in the CREZ network. “There's no regulatory agency, no permitting, no wind laws,” says Rod Wetsel, an attorney in Sweetwater who specializes in wind leases and who cowrote *Wind Law*, the definitive text on

Russ Petty at the door to one of the turbines that Invenergy operates under a lease with his family.





the legalities of wind power. “It’s like prospecting: you can basically go stake your claim and build your project.”

That means you can also lose your shirt. Billionaire oilman T. Boone Pickens was forced to back out of his grandiose plans for the world’s largest wind farm, in north Texas, after spending more than \$2 billion—essentially because he was too early to market. “That was pre-CREZ,” Wetsel says. “If he’d waited a few years he’d have been fine.”

UNSTOPPABLE

A pair of snow-white cattle egrets winged across a field of alfalfa as I pulled up to the Clear Crossing Substation, 30 miles from the nearest town in the empty scrubland of Haskell County. Built at a cost of \$42 million by Electric Transmission Texas, a joint venture between American Electric Power and Warren Buffett’s Berkshire Hathaway Energy Company, Clear Crossing is a 345-kilovolt switching station, a waypoint on the web of CREZ lines that stretches from Amarillo to San Antonio, 500 miles to the south, and from Odessa 350 miles east to Dallas. Clear Crossing collects power from the lines that run from the wind farms in the north and west and sends it east. The power lines hummed in the 100° day as Greg Blair, an AEP spokesman, and I stood contemplating the 40-acre complex of circuit breakers and wires. Across the road a large solar farm, owned by San Antonio’s municipal utility, was under construction.

“There’s plenty of wide-open spaces out here for big projects like these,” Blair remarked in a Texas-sized understatement.

Electric Transmission Texas has built more than one-fifth of the 3,600-mile CREZ system in the past decade. That system is Texas’s answer to the basic quandary of wind power: the best wind for generating electricity is in remote places where no one wants to live, in part because it’s so damn windy. Without CREZ, there would be no wind boom in Texas.

CREZ was built under Rick Perry, the small-government Republican governor who ran the state from 2000 to 2015. It’s clear now, says Jeff Clark of the Wind Coalition, that CREZ “should be recognized as one of the most visionary infrastructure projects ever built in Texas.”

It was possible because Texas is the only U.S. state with its own power grid. The continental U.S. has three primary grids: the Eastern Interconnection, the Western Interconnection, and the Electric Reliability Council of Texas, or ERCOT. The first two cover multiple states, while ERCOT operates in Texas only, covering three-quarters of the state. It can invest in and build long-distance transmission lines as it, lawmakers, and state regulators see fit, without the interstate political wrangling that has blocked other ambitious long-distance transmission projects planned across state lines.

So unstoppable is the Texas wind boom, though, that even the CREZ system is starting to reach full capacity. At particularly windy times, some wind farms have ended up being effectively stranded, without a way to get power east to the cities.

Top left: A Texas state waffle, common in complimentary hotel breakfasts in Sweetwater.

Bottom left: A tumbleweed blows down a gravel road near the Mesquite Creek wind farm.

Below: Rod Wetsel, wind lawyer and long-distance motorcyclist, in a cotton field that doubles as a wind farm.





A ripe cotton seed,
ready for harvest.



A sign outside a church in Harper reflects the area's traditional reliance on cotton farming.

That happened to one of Invenergy's wind farms in January, when congestion rose on the transmission lines and it could not export its electricity—even when it offered to pay utilities \$22 per megawatt-hour to take it. Meanwhile, new solar projects in the region are expected to add another 2,200 megawatts of capacity, with an additional 7,000 under study. Having spent billions of dollars on a transmission system, the state is now faced with spending hundreds of millions more to expand it—a demonstration of just how costly and complicated it is to shift from fossil fuels to renewable energy, even where the conditions are optimal.

TOO MUCH WIND?

Even if wind farms sometimes have to pay customers to take power off their hands, they can make money because of the federal tax credit for wind developers. But that subsidy will begin phasing out next year before expiring completely in 2020. That's when the true economics of wind power will become evident. Power from wind generally remains more costly than power from fossil fuels. Especially at today's low electricity prices, driven by a glut of natural gas, it's hard to envision how all these new wind farms sprouting in the badlands can be competitive without "significant direct and indirect support at the state and federal level," says Kenneth Starcher, former director of the Alternative Energy Institute at West Texas A&M University.

Then there are the physical challenges. Although it might seem as though someday getting 35 percent of the nation's power from wind is feasible, relying on wind for more than 20 or 25 percent of the total is difficult because of wind's variability, which affects the system in multiple ways. Since the grid operator must match supply to demand on a minute-by-minute basis, reserve power—mostly natural-gas plants, these days—must compensate when the wind stops blowing, ramping up quickly to fill in the gap. (That can also happen when there's too much wind: when it blows harder than 64 miles an hour, the turbines shut down to prevent damage.) Requiring generators to keep fossil-fuel plants running even when there's no market for their power effectively adds to the overall cost of wind. Wind's variability also affects the power quality—the ability of the grid to provide electricity within certain ranges of voltage and frequency.

Because of such problems, the eastern half of the U.S. could not rely on intermittent renewable sources for more than one-third of its electricity even with massive investments in new transmission lines, according to a new study from the National Renewable Energy Laboratory.

"Is it possible to have too much wind, in terms of problems or challenges the system operator will have? The answer is yes, absolutely," says Bill Cannon, vice president of the U.S. division of Sumitomo, which has built and owns wind farms. "The more wind you have, the bigger the challenge. As far as what is the perfect amount of wind, I don't think anybody has that answer."



Above: Cows graze near Nolan.

Right: An older wind technology on display in the town of Coleman.







The sun rises over the Caprock on
the Mesquite Creek wind farm.



Oil was discovered on this ranch in the 1950s. The well still operates but today is surrounded by turbines.

Technological advances in energy storage, grid operations software, and wind turbines could make it possible to integrate more and more wind power. But how much? That answer will almost certainly be found in Texas over the next five to 10 years. And that will have profound implications for the future of wind power. Because if Texas can't incorporate much more wind power, it probably can't be done anywhere. Beyond the transmission lines and the nearly statewide grid, Texas has plenty of unoccupied territory for huge, expansive wind farms. You don't have that on the eastern seaboard, or in the deep South, or even in California, where real estate is expensive and nearly all the wind-generating capacity is clustered in three areas. Offshore wind farms are another possibility, but they carry transmission and political challenges that have, so far, limited their scope in the U.S.

There's also something less tangible in Texas, something about the culture. Texans have never been afraid of living close to big energy infrastructure, whether it's the pumpjacks of the Eagle Ford shale formation or the huge refineries of the coast. The opposition to Big Wind in other states, where turbines are considered bird-killing eyesores, isn't a factor. Ultimately, the wind boom here may underline the limits of renewable energy as much as it highlights the possibilities. As Kenneth Starcher says: "Texas is its own place." 📌

Richard Martin is the author of Coal Wars: The Future of Energy and the Fate of the Planet and SuperFuel: Thorium, the Green Energy Source for the Future.

Elon Musk's

The founder of Tesla, SolarCity, and SpaceX is deservedly admired for his technological insight. But is his latest business plan reckless?

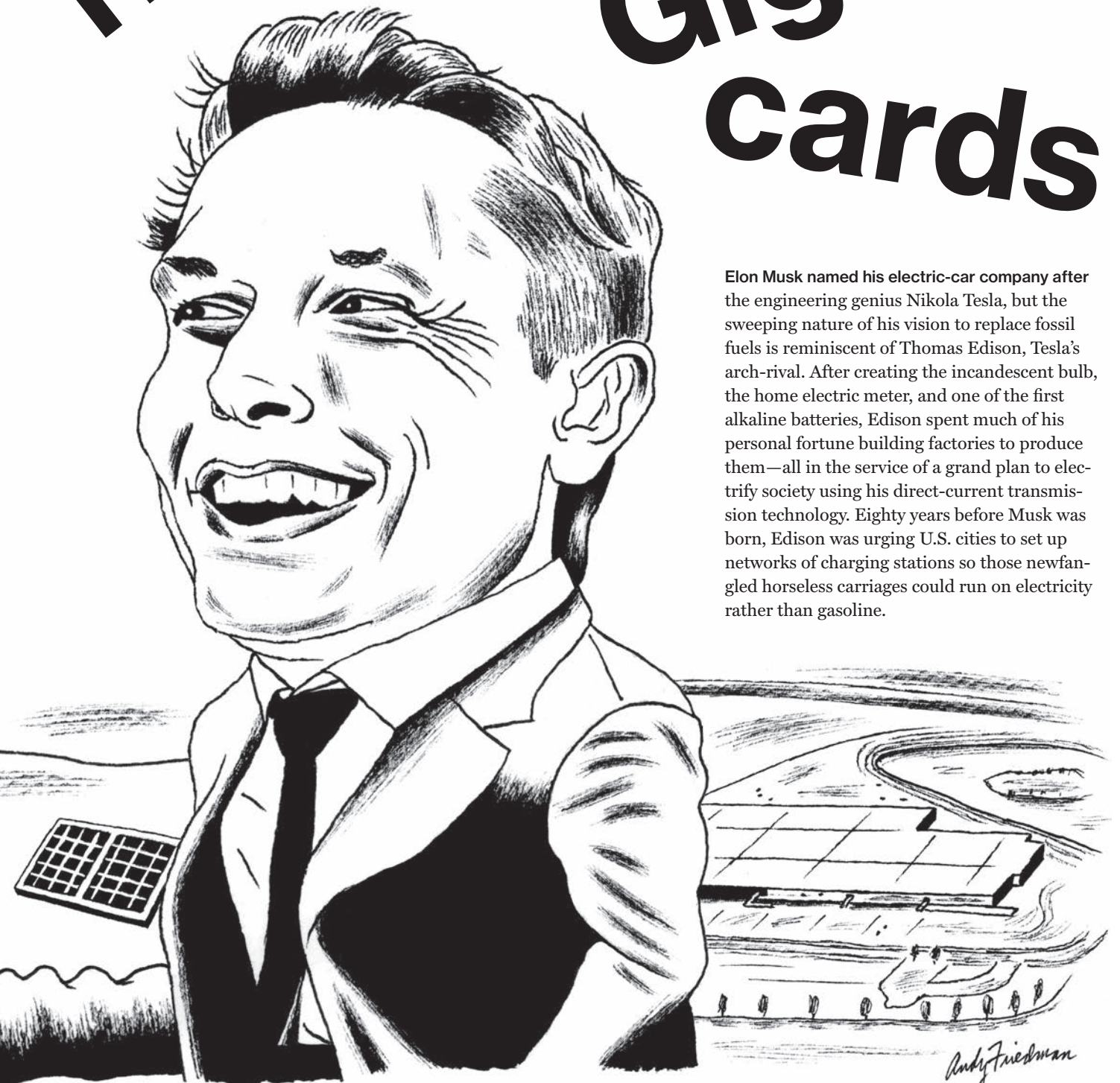
By Peter Burrows

Illustration by Andy Friedman



House of Giga-cards

Elon Musk named his electric-car company after the engineering genius Nikola Tesla, but the sweeping nature of his vision to replace fossil fuels is reminiscent of Thomas Edison, Tesla's arch-rival. After creating the incandescent bulb, the home electric meter, and one of the first alkaline batteries, Edison spent much of his personal fortune building factories to produce them—all in the service of a grand plan to electrify society using his direct-current transmission technology. Eighty years before Musk was born, Edison was urging U.S. cities to set up networks of charging stations so those newfangled horseless carriages could run on electricity rather than gasoline.



For Musk's fans and investors, the comparison should not be entirely comforting. In the course of a few short years, the Wizard of Menlo Park was unceremoniously forced out of the electricity game. After he stubbornly refused to embrace the transmission technology that became the foundation of the U.S. grid and focused increasingly on developing inventions such as the phonograph and the motion picture, his board of directors merged his Edison General Lighting with a rival to create today's General Electric—leaving the 46-year-old Edison with no management role. “Many great innovators are great at introducing new things but not so great at adapting to market changes,” says Paul Israel, director of the Thomas A. Edison Papers, an archive at Rutgers University. One could argue that he “got too distracted” from his power plan, Israel adds.

Many Tesla Motors investors are wondering if Musk, 45, has begun to lose his way as well. This summer the company was already burning through billions of dollars as it constructed a battery factory in Nevada that will be

the largest building in the world and prepared to deliver its first electric car for the masses, the Model 3. Then in July he announced that Tesla would buy the solar-panel provider SolarCity for \$2.6 billion in stock. As he wrote in a blog post titled “Master plan part deux,” the combined company will generate power for customers on stylish roofs with embedded solar panels, store it in Tesla battery modules, and, of course, use some of it to power Tesla vehicles. The company won't just sell traditional cars, mind you; it plans to introduce an expanded portfolio of autonomous models, including a new type of small bus and an 18-wheeler. Musk has also described a ride-sharing service, in which Tesla customers make their self-driving cars available when not using them.

And he's pursuing all this while running the commercial rocket maker SpaceX, which lets him pursue his life's dream: enabling mankind to colonize Mars. In September he revealed plans to create a fleet of rockets capable of taking 100 people at a time to the Red Planet for around \$200,000 per ticket.

“You have to respect his chutzpah, but that doesn't mean it's going to be successful,” says Jigar Shah, a former solar industry executive and cofounder of Generate Capital, which invests in sustainable-power infrastructure.

The Tesla-SolarCity deal looks so bad on paper that many investors worry it's simply a bailout of SolarCity, which Musk cofounded and continues to chair. Fellow cofounders Lyndon and Peter Rive, the CEO and chief technologist, are Musk's

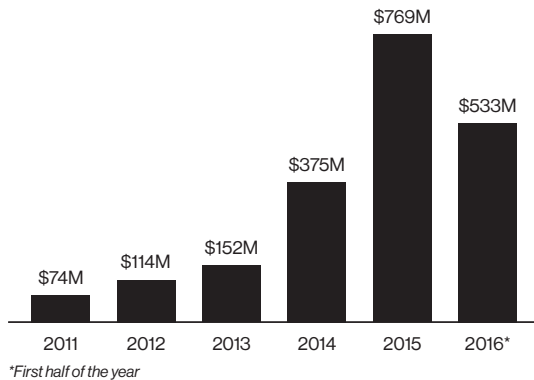
cousins. While SolarCity dominates the market for leasing, installing, and maintaining solar panels for residences and businesses, it's racked up more than \$2 billion in losses over the past five years. Its business model requires it to raise huge amounts of capital to cover the up-front costs of providing panels for no money down to consumers on multi-

year contracts. Since its inception, the company has accumulated more than \$3 billion in debt against just \$1.5 billion in revenue. Now it is having a harder time convincing people to lend it money. The company recently offered “Solar Bonds” at a cushy 6.5 percent interest rate, sending e-mails to its customers to invite them to invest. “Nobody bought it,” says Ross Gerber, president of the investment firm Gerber & Kawasaki, which also passed on the deal. Instead, Musk and the Rive brothers bought \$100 million of the \$124 million bonds on offer. There was a similarly friendly buyer for \$165 million worth of Solar Bonds last year: SpaceX, which has committed to loan SolarCity another \$90 million. SolarCity also raised \$305 million by selling future cash flows to a fund advised by billionaire George Soros.

Tesla is no exemplar of financial stability either. It's lost \$2.5 billion in the last five years, even more than SolarCity. It

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SolarCity's Net Losses

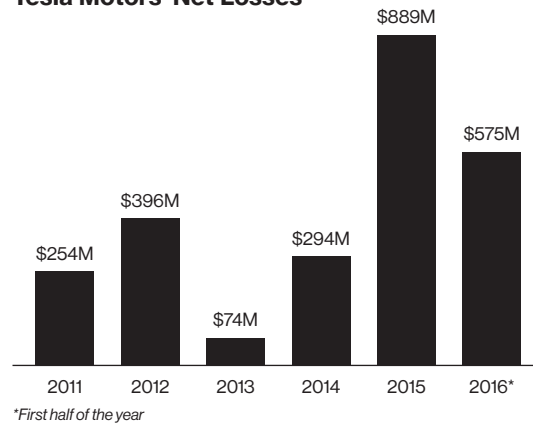


hasn't had a quarterly profit since 2013. This summer Musk beseeched employees to cut costs so the company could get back into the black in the third quarter before it begins burning cash again as it races to complete the Model 3 factory and the huge battery "gigafactory" in Nevada. "The simple reality of it is that we will be in a far better position to convince potential investors to bet on us if the headline is not 'Tesla Loses Money Again' but rather 'Tesla Defies All Expectations and Achieves Profitability,'" he wrote in a memo to the entire company. "That would be amazing!" (Musk declined to comment for this story.)

It also would be amazing if he could get the financing to pull everything off. Analysts think Tesla will need to raise \$1 billion or \$2 billion in the next year to build the Model 3 and develop the bus and the 18-wheeler. If it goes ahead with the plans to buy SolarCity, which is in the process of building a gigafactory of its own in Buffalo, New York, it could need \$3 billion or \$4 billion in that time, Gerber says. Earlier this year, Musk said his grand plan would cost tens of billions of dollars, although he didn't say how much of it he expected to finance from the company's cash flow. That's a main reason Tesla shares dropped 10 percent in the two months after the merger was announced. "I'd only invest if I knew the money would only be used by the Tesla side," says Gerber, whose firm has sold 20 percent of its stake in Tesla since the SolarCity deal was announced. He's hoping Tesla or SolarCity shareholders kill the merger when they vote this fall. "The last thing a cash-flow-negative company needs is another cash-flow-negative company," Gerber says.

A debacle for Tesla would be a shame for anyone who is building technologies meant to combat global warming. No one has done more than Musk to spur demand for electric cars and residential solar power, disproving naysayers by reaching milestones once thought unattainable. If the SolarCity deal proves to be one big hairy audacious goal too far, he could

Tesla Motors' Net Losses



make life far more difficult for other green-energy entrepreneurs, who already struggle to raise funds to pursue ambitious long-term goals. Perhaps if Musk flames out or just muddles along, future entrepreneurs will be told, "Oh, please: even Elon Musk couldn't make green tech work."

No more glitches

At this point, any investors who believe that Tesla and SolarCity ought to be combined are giving Musk the benefit of the doubt. He has already written himself into the history books alongside Edison for a series of epic accomplishments. Tesla's Roadster, unveiled in 2008, wiped the boring off of electric cars with its stylish design and record-setting acceleration—faster than any Porsche, going from zero to 60 miles per hour in 3.7 seconds. He earned his rep as a real-life Tony Stark from his work as CEO of SpaceX, which is threatening to revolutionize space travel with rockets that cost a fraction the price of those operated by state space agencies such as NASA. SpaceX was the first private company to deliver a satellite into orbit, and the first to build a rocket that could launch payloads into orbit and make a return trip so it could be used again.

While Musk is often compared to Steve Jobs for his ability to shake up hidebound industries, he doesn't share the Apple cofounder's reticence about predicting the future. Musk says the opportunity in sustainable energy is so large that Tesla could be the first company in the world to be worth more than a trillion dollars, surpassing even Apple's \$600 billion valuation.

For anything close to that to happen, many unlikely things need to work out incredibly well. Job one is to deliver the Model 3 on time and glitch-free. Musk says that it will have a base price of \$35,000—roughly half the price of Tesla's cheapest car today—and will begin shipping next July. More than 373,000 people have plunked down \$1,000 to preorder the car. But Tesla has missed its delivery target on its first three

“The last thing a cash-flow- negative company needs

cars by an average of 11 months. And the stakes are higher this time. While Tesla had the market mostly to itself in the past, all the big car companies are rushing electric vehicles to market. Even if Tesla remains the iPhone of electric cars, plenty of people will opt for more yeoman-like models such as the Chevrolet Bolt.

Moving from affluent early adopters to mainstream buyers will require Tesla to improve the quality of its cars. Its first three models have had a variety of bugs, from faulty drivetrains to body panels that don't align properly. Until a recent software fix, the falcon-wing doors on the Model X SUV sometimes refused to close because they erroneously detected objects in the way (now they've been compared to guillotines, since they are more apt to close regardless of obstructions). Musk told analysts in August that the quality of the cars was rising “quite dramatically,” even as the company's weekly production passed the 1,000 mark.

The problems haven't seemed to bother Tesla's early adopters, including many wealthy Silicon Valley techies. Despite poor reliability ratings from *Consumer Reports*, Tesla's Model S enjoys the highest customer satisfaction score among all cars on the market, says Jake Fisher, director of auto testing for the group. But mainstream consumers won't be as forgiving, predicts Horace Dediu, an analyst with Asymco: “If your mission is to change the world, you have to cross the chasm from people who are tolerant of being abused to people who are not tolerant of being abused.”

The most difficult challenge will be to meet Musk's aggressive plans to increase the production capacity of Tesla's factory in Fremont, California, from 50,658 cars in 2015 to 500,000 in 2018 and a million in 2020. While the company shows off its robots and automated processes during tours of the facility, basic math suggests it is one of the more labor-intensive plants in the car business—as does the daily competition for scarce spots in the vast parking lot. A typical 3,000-employee factory might make 250,000 or so cars in a year, but the 6,000 workers in Fremont will build around 80,000 this year.

Musk says the Tesla factory will roll out a radical, as-yet-undisclosed manufacturing process that will look as familiar to traditional carmakers as an “alien dreadnought.” With smarter placement of equipment and improved processes, the company believes, it can deliver a fivefold improvement over the most efficient existing car factories. The plan will also depend on the smooth ramp-up of battery production from Tesla's gigafactory 240 miles to the east near Reno, Nevada. Now roughly 15

percent complete, the building will be as large as 100 football fields and have the capacity to double the worldwide production of lithium-ion batteries.

Buying SolarCity will put another major manufacturing challenge on Tesla's plate. SolarCity, founded in 2006, got big by getting homeowners to lease panels made by low-cost suppliers, mostly in China—a hyper-competitive market that has destroyed dozens of startups. Profit would come by charging the customer more over the life of the contract than the cost to finance, install, and service the panels, and by selling excess energy back into the grid. Flush with growth, SolarCity was also able to securitize its leases, much as Wall Street banks do with mortgages, by bundling them into financial instruments that it could sell to investors willing to put up cash in exchange for future cash flow from those leases.

In recent years, with panel prices continuing to plunge, more customers have decided it's a better deal to buy their solar setups outright rather than lease from companies like SolarCity. So in 2014, the company changed course and bought Silicon Valley-based Silevo, which makes panels that are better-looking and slightly more efficient at converting sunlight to electricity than commodity models (see “10 Breakthrough Technologies: SolarCity's Gigafactory,” March/April 2016). With the help of \$750 million in incentives from New York State, the company decided to quintuple the output of a plant Silevo had planned to build in Buffalo. SolarCity expects that Silevo's technology will give it an edge in the solar business. But if it can't keep pace on price or deliver a truly differentiated product, the panel factory could become a boat anchor.

“That’s not how people think”

“Master plan part deux” relies on a bold new sales and marketing strategy as well. Rather than continue hiring thousands of door-to-door and telephone reps to sell solar panels, Tesla intends to push SolarCity’s business through its rapidly growing chain of retail stores by converting them into one-stop shops for environmentally conscious consumers. Instead of buying an electric car only to have it use electricity from a far-off coal plant, a customer would be able to lease or buy solar panels as well as Tesla Powerwall storage units so power is available on cloudy days and at night—or to sell back into the grid. Musk hasn’t provided details on what such a package would cost, but Shah, the Generate Capital executive, thinks Tesla could charge \$900 a month on a 20-year contract to get a Tesla, a solar roof, a storage unit, and the right to upgrade to a newer-model Tesla twice during the life of the contract.

Like so much else with Elon Musk, the vision is elegant and ripe with potential. So far, only 100 million of the world’s 2.5 billion cars are electric, and only 1 percent of U.S. homes have gone solar. Sales of the Powerwall and a higher-capacity version designed for businesses have been disappointing. Tesla says production problems are to blame, though it’s not clear that fixing those issues will be enough make the Powerwall a cost-effective way to run a home entirely on solar power. But if consumers do decide to buy these soup-to-nuts renewable-power setups, and if solar penetration rises to 15 percent, as it has in Australia in recent years, the overall market opportunity just in the U.S. will be \$470

**is
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billion, says Shah. And Tesla is also hoping to become a leading provider of equipment and services to large utilities. The company recently announced a deal to provide 20 megawatts of power storage to Southern California Edison for the “largest lithium-ion battery storage project in the world.”

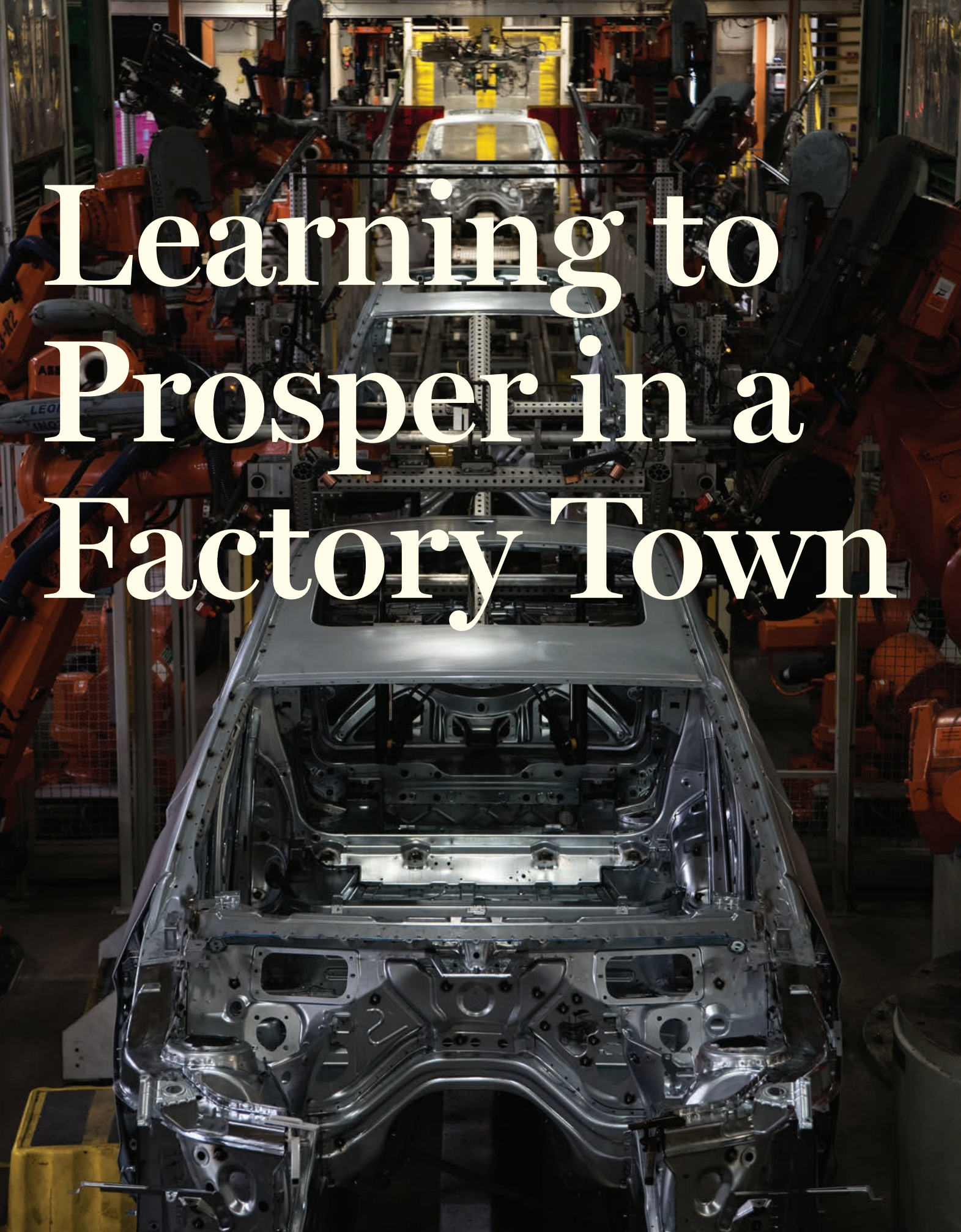
That said, Tesla has yet to show it can build a world-class industrial sales organization. And how many people are really going to go to their local Tesla store and buy in to Musk’s dream? Even Tesla’s affluent true believers might balk, says Gerber. “Elon seems to think that green-minded rich guys like me will decide to put solar on my house, and buy a car or two while they’re at it,” he says. “That’s not how people think.” What’s more, 63 percent of homes in the U.S. are not owned by the resident but by landlords or condo associations, according to the National Multifamily Housing Council. These owners have little incentive to invest in solar and storage.

Possibly the biggest risk is that Musk loses credibility by taking on so many huge challenges at once. While he’s delivered on many bold product promises in the past, his luster could fade with a few well-publicized misses. Tesla is facing criticism for the aggressive way it marketed its Autopilot feature, leading some people to believe they could leave the driving to the car. “They’re pushing hard to be seen as being on the leading edge, and I’m not sure safety is their number-one priority,” says Fisher of *Consumer Reports*. After a Florida man was killed in May, Tesla updated the cars’ software so that drivers who ignore too many warnings to keep their hands on the wheel won’t be able to reactivate Autopilot for the rest of the trip.

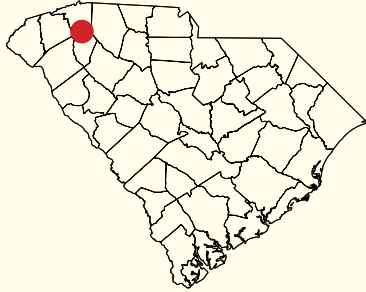
Just how safe Tesla investors are is another matter, judging from the daunting degree of difficulty facing Musk. Many investors think Tesla was assuming appropriate levels of risk with its crisp plan to take on Detroit. Others believe the company’s best opportunity is to become the leading maker of batteries for storing solar power and powering multiple manufacturers’ electric cars. That could be lucrative even if Musk can’t dominate the electric-car or solar-installation businesses. But unless shareholders shoot down the SolarCity merger, Tesla investors will not be taking one of those routes.

Instead, Musk will ask them to go along with something far bolder. His record as an innovator and visionary is beyond question. But the next year or two will determine whether he can do what Edison failed to do: translate his sweeping vision into historic business success. ▣

Peter Burrows is a business journalist in California who wrote about Intel and deep learning in the July/August issue.



Learning to Prosper in a Factory Town



By Nanette Byrnes
Photographs by Stacy Kranitz

Greenville, South Carolina, has bet its future on high-tech manufacturing. Who wins and who loses in this increasingly automated economy?

In the foothills of the Appalachian Mountains in a corner of South Carolina sits a town that should be economically dead. For decades, Greenville was the heart of the state's textile industry—and its economic engine. First attracted by the area's fast-moving rivers as a way to power looms, textile manufacturers employed tens of thousands of people here. Beginning in the 1970s, however, facing competition from lower-cost manufacturing regions like Mexico and Southeast Asia, these companies began to struggle. Over the next decades, many factories closed. Others moved production overseas. In 1990, 48,000 people

still worked in textile manufacturing in the Greenville area, according to the U.S. Bureau of Labor Statistics. Today fewer than 6,000 do.

Yet Greenville is booming. Visit its pretty downtown and you will find runners pushing jogging strollers and tourists snapping shots from the pedestrian bridge across the Reedy River in Falls Park. On Main Street you can eat at nationally recognized restaurants. A flock of construction cranes spend the days erecting pricey new condominiums. In recent years, the city and its surrounding counties have benefited from large increases in tax revenue and improved funding for local schools.

While Charlotte, North Carolina, a 90-minute drive to the northeast, bet on financial services as the centerpiece of its economy, and other cities have tried to cultivate software hubs or tourism, Green-

ville has remained focused on manufacturing. Major global manufacturers with outposts here include BMW, ABB, Fluor, Michelin, Bosch, and General Electric's power division. As local factories have adopted increasingly computerized and automated techniques, the region has evolved into one of the country's leading centers of advanced manufacturing.

The payoff for Greenville has been a strong economy by many conventional measurements. Though it sank with the rest of the country during the recession, it has bounced back since. Unemployment today is below the national rate at 4.7 percent, and median household income and property values have risen in recent years. Between 2010 and 2014, \$1.5 billion was invested in businesses in the county, which added 8,947 new jobs. New businesses are being created here faster than anywhere else in the southeastern U.S., according to data tracked by the South Carolina Department of Commerce.

But there is a downside to this transformation of Greenville's economy. Increasingly, these modern factories are dominated by machines, employing far fewer people than textiles once did. For those workers still on the factory floor, jobs are changing too, requiring new skills. Those without such training are being left behind.

In 2004, the Greenville area's per capita income was 83 percent of the U.S. average. Today it's fallen to 80 percent of the national average. The number of people collecting food stamps has doubled over the past decade. Even in this boom, 21.5 percent of children in Greenville live in poverty—and the county has traditionally been one of the toughest places in the country for a child to climb out of poverty, according to research led by academics at Stanford and Harvard. That research did not draw specific conclusions about what has created this problem in Greenville,

but if trends seen across the country also apply here, its origins likely lie in a lack of opportunity caused by factors such as higher rates of poverty, economic segregation, poor housing conditions, and crime.

In some ways Greenville exemplifies the future for communities built around advanced manufacturing. The changes in factories and factory work under way in manufacturing centers across the U.S. and Europe, and even beginning to accelerate in once low-cost manufacturing meccas such as China, are boosting local economies, but they're also demanding that workers make the transition to jobs that require far more computer and technical skills. In an election year in which economic dissatisfaction, particularly in traditionally blue-collar cities, has been a dominant theme, Greenville illuminates what can be expected—and what can't—from a factory-focused economy in a digital, automated age.

New skills

When politicians refer to manufacturing as a source of numerous jobs, they're talking more about what manufacturing once was than what it is today. Modern manufacturing is a story of increasing output but slowing employment growth. That's because investment in automation and software has doubled the output per U.S. manufacturing worker over the past two decades. During that period, overall manufacturing output grew by 40 percent, despite a nearly 30 percent decline in the number of manufacturing jobs.

Computerization and modern production have created new types of factory jobs, many of which pay more than the old ones. They just haven't created as many of them. As a result, competition for the new jobs can be intense. And just as Greenville has had to adapt to a different type of manufacturing, its people have had to adjust to a new type of factory work.

When Shauntae Stewart decided to go back to work after 12 years at home with her children, her first job was working as a contractor at the BMW plant, inspecting parts from suppliers as they were about to be installed on the assembly line. The work paid \$9 an hour.

It wasn't long before Stewart quit to join a program, sponsored by a group called Greenville Works, that pays for workers' training in skills needed by local manufacturers. She learned to operate a machine that makes parts based on computer instructions. Now she earns \$24 an hour at Baldor Electric, a division of ABB that makes electric motors, where she spends her days operating a lathe and a grinder, reading the blueprints for the parts and checking that the machine is making them to the proper specifications.

Stewart grew up in Greenville. Her aunt used to work in the textile mills. Now she's become a kind of advanced-manufacturing evangelist. "I see a waitress at the Waffle House who doesn't look satisfied, or someone at the gas station. I give them my name and number. I tell them you don't have to stay here in this dead-end job," she says.

But making that transition can be difficult. When the economy began to improve following the recession of 2007 to 2009, many people who had worked in manufacturing and lost their jobs had trouble getting back into factory work. They either lacked the requisite credentials or were not familiar with the newer manufacturing technology, explains Amanda Warren, a counselor who works on employment readiness at United Ministries, a Greenville nonprofit. Those who were hired were most likely to get their jobs through contractors, as temporary workers who could more easily be added or let go.

The stark reality is that the arithmetic is not favorable to people who might once have worked in manufacturing as a

“There’s some things that might need that human touch.”

An aerial view of the BMW plant in Greer, South Carolina. Already producing more cars than any other BMW factory, it is now adding a new body shop.





Families enjoy Falls Park in Greenville (top) and the Upper South Carolina State Fair at the NASCAR Greenville Pickens Speedway.

way to a middle-class life. Whereas the textile mills of earlier days had a seemingly endless appetite for workers, today many are left out of the factory boom and must scrape by on low-paying service jobs.

"Some workers will be displaced. Some people will have to be retrained, even in the best of cases," says Marco Annunziata, chief economist for General Electric,

which has both a large gas-turbine factory and a new advanced-manufacturing research center in Greenville. The changes are inevitable, says Annunziata, because "the [business] incentives are just overwhelming" to take better advantage of digital technologies. Asked how communities like Greenville will manage this evolution, he says, "I am worried and optimistic at the same time."

It's not just that people need certain technical skills to work in these new factories. They must also have softer skills, like the ability to solve problems and work in teams. Three years ago Solvay, a Belgian chemicals and materials manufacturer, decided to hire 100 new people for its plant in Greenville, which made carbon fibers in growing demand from customers in the aerospace industry. It made the

These doors will be picked up by robotic arms and welded onto car bodies in the BMW plant's body shop. Today 99 percent of the work in this part of the plant is done by robots, up from 30 percent 20 years ago.



ability to work collaboratively a key focus of the interviewing process. “We are looking for not just mechanical and industrial skills but also the ability to look beyond what’s right in front of you,” says Kelly Kosek, the human resources manager at Solvay. “You don’t just punch a clock on your job and check out.”

Renda Fant was one of those hired by Solvay, in October 2013. Fant had worked

for 17 years for a local supermarket chain before it moved its headquarters to Florida. Today she spends her shifts on a team of five people testing the quality and physical properties of the carbon fibers made in the plant. It took her a year to feel expert in the 50 different tests she performs, and she still hasn’t gotten used to the swing-shift schedule, but Fant is making \$28 an hour, almost twice what she



More than 100 robotic arms spray-paint the car bodies in the BMW paint shops, alternating from one color to the next. The 12-hour process of painting each car is monitored by a computerized tracking system. There are five coats of paint, the combined layers as thick as five human hairs.



Many residents earn extra income at the large flea market in Pickens County, a former textile center near Greenville.

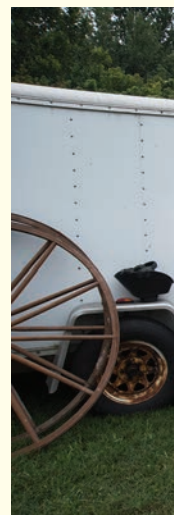


earned at the supermarket. And she says learning the process at Solvay, something that at first seemed like mastering a foreign language, “fills up your self-esteem.”

99 percent robotic

With more than 8,000 workers at its factory in Greer, South Carolina, a Greenville suburb near the airport, BMW is one of the larger local employers. It also uses a lot of robots. A day spent in the factory shows the company striking a balance between automation and human skill, while constantly searching for ways technology can improve the production process.

Since setting up shop in South Carolina, where the company established its first full factory outside of Germany in 1994, BMW has invested \$7.4 billion in the facility. Much of that has gone to increase its use of automation, starting with the 1,400 robots in the factory’s body shop. The factory makes 1,400 cars a day, almost one every minute. It produces the company’s popular X series sport-utility vehicles and is now the largest BMW plant in the world.





Two decades ago, when this plant opened, the body shop was full of human welders soldering together the framing of the car. Today it's a dimly lit place where large robotic arms, switching on and off without human assistance, easily lift heavy car bodies of steel and aluminum like giant orange storks. When the plant opened, robots did 30 percent of the work in the body shop. Now they do 99 percent of it. The few people you see in the shop are mainly delivering components the robots need and checking banks of computer monitors that track the machines' work.

By contrast, the plant's assembly line is full of people. This is where the painted

shell gets its engine, wiring, interior, and wheels to become a recognizable car. Here people surround the car, sometimes working next to it, other times beneath it— assembling the power train, installing the fuel tank and fuel lines, placing seats and carpeting, and finally testing the vehicle. These tasks require a level of dexterity and flexibility that robots have not yet mastered.

The cars made in Greer are highly customized: all of the 400,904 vehicles made here last year were manufactured to exact customer specifications. With all those variations, there's a certain amount of human assessment required. All along the line, workers and supervisors peer at

“I am
worried and
optimistic
at the same
time.”





In the BMW body shop, robots weld car frames together, monitored by employees outside cage walls.



*Top: Manuel Gonzalez did not like the new field of mechatronics and is now becoming a machinist.
Bottom: Falls Park.*

Top: A Sunday afternoon at the driving range. Bottom: The Shoeless Joe Jackson baseball field and park in West Greenville.





Assembling cars at BMW's factory in Greer, South Carolina.

cars from different angles, running their hands over them, judging whether they look and feel right.

Humans have a feel, an instinct, that it's hard to imagine replicating in a robot at a cost that makes sense, says Gadrian Zayas, a manager of BMW's worker training programs: "There's some things that might need that human touch."

In a few spots along the line, robots and humans work side by side. When the doors are assembled, they make one stop at a small robot that rolls foil along the interior of the door, making a watertight

seal. It's a repetitive task that requires enough force and work at strange angles to cause thumb and wrist injuries and other ergonomic problems in the people who used to do it. Unlike the orange giants in the body shop, which must work inside locked cages to protect human workers nearby, these robots can sense and respond to the presence of a person, stopping before they come into contact.

Made by Universal Robots, a Denmark-based manufacturer of collaborative robots, the machines are flexible and can be reprogrammed quite easily to

do different things. Now BMW is testing ways they can work more collaboratively with people, including handing a tool to workers when they ask for it.

Other technologies being tested on the floor include an autonomous vehicle that could replace a forklift, and an exoskeleton vest that helps workers keep their arms above their head when drilling screws into the bottom of a car. "We are not replacing people," says Richard Morris, vice president of project integration at the factory. "We are using the automation to help them."

“Some workers will be displaced. Some people will have to be retrained, even in the best of cases.”

Although it's easy to imagine a future in which at least some of the work done by humans on the assembly line today is done by robots, manufacturing plants like the BMW factory will still need thousands of workers. And for a city like Greenville, preparing people for those rapidly changing jobs is both a challenge and an opportunity.

In September, Greenville Technical College opened a glass-and-steel building with soaring ceilings and hard concrete floors, its main classrooms populated with computerized machinery: 3-D

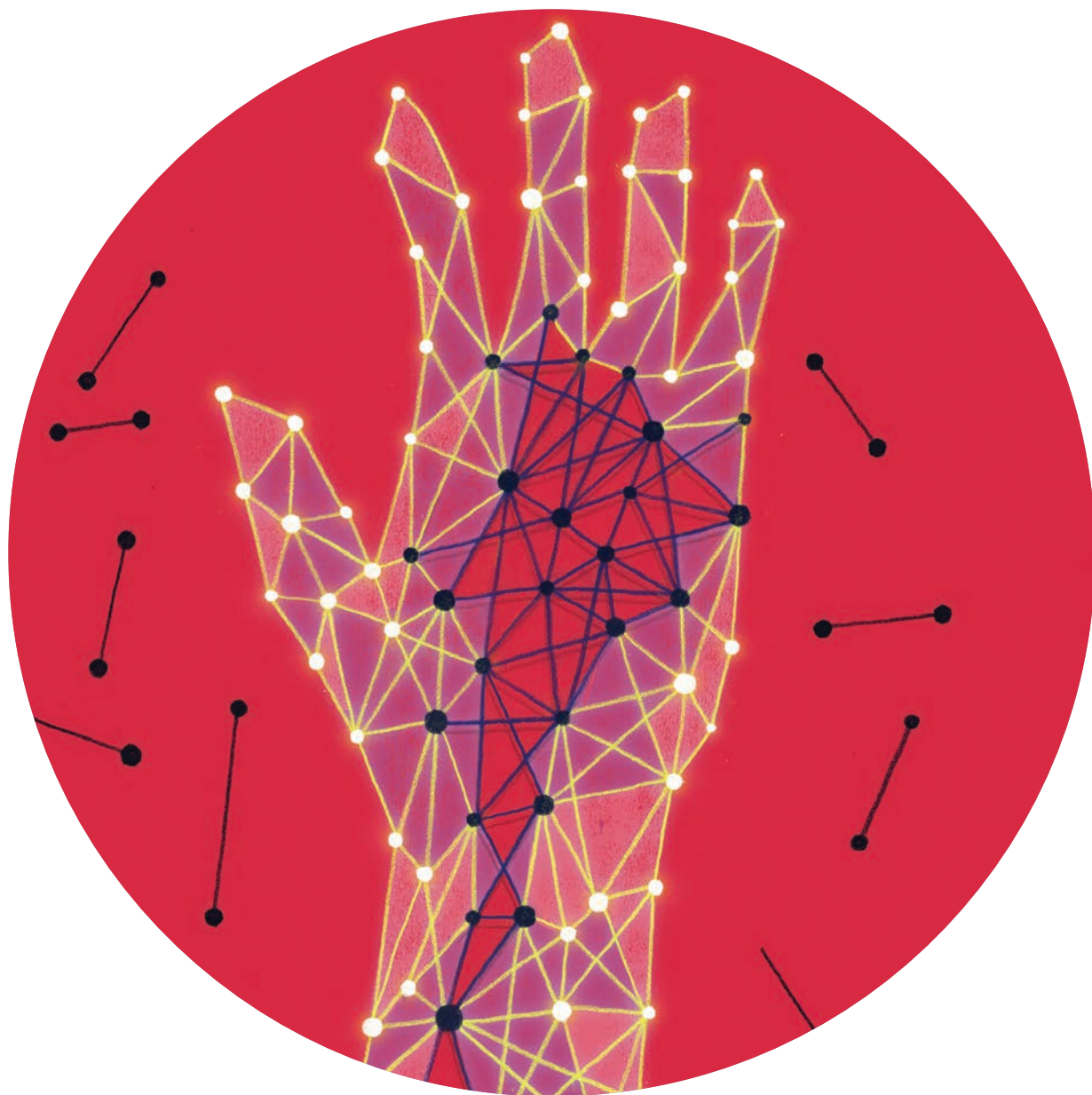
printers, computer-driven machining tools, robotic arms. Community college students, many studying for new degrees that combine mechanics and electronics, collaborate with engineering students from nearby Clemson University to study a type of manufacturing where design and execution are closely linked.

It's a dazzlingly different vision from the repetitive manufacturing lines of the past—and for Greenville County, which borrowed \$25 million to build the facility, it's a big bet on a new type of factory work.

“Manufacturing has changed,” says Keith Miller, president of Greenville Tech. “Students need to be more flexible. And we needed a different approach.”

For communities like Greenville that have hitched their economic prospects to advanced manufacturing, automation and computerization will continue to transform both their factories and the work done within them. The only option is to adapt. ■

Nanette Byrnes is MIT Technology Review's senior editor for business.



Can CRISPR Save Ben Dupree?

Scientists are rushing to figure out how to use the gene-editing tool to stop devastating diseases like muscular dystrophy.

By Antonio Regalado
Illustration by Dadu Shin

At 24, Benjamin Dupree has outlived many people with Duchenne muscular dystrophy. It was diagnosed 15 years ago, after he struggled to get up the stairs without using the banister. Doctors say the disease is terminal, but they tell you little about living with it. About the girls who don't see past your wheelchair, or how the phone stops ringing. It's you and Mom counting the birthdays and figuring out what you can't do this year. Dupree says he got by in high school, but in college depression gripped him. "I didn't know how I could keep going," he says.

The problem is that Dupree's body doesn't make dystrophin, a protein in muscle fibers that acts like a shock absorber. Without it, your biceps, calf muscles, and diaphragm slowly turn to a fatlike substance. You end up on a ventilator, and then your heart stops. Dystrophin is manufactured by a gene that is not only the largest in the human genome but the largest anywhere in nature. It consists of 79 components known as exons, each an instruction for one ingredient of the protein. Dupree's problem, he told me, is a "pseudo" exon—it's as if in the middle of this epic recipe someone had added a mistaken instruction that read, "Stop the cooking." There are thousands of ways a gene this size can go wrong, and Dupree's mutation—a single letter of DNA that reads 'G' instead of 'T'—is unique, so far as scientists know.

Dupree, who majored in biochemistry and hopes to become a genetic counselor, has sometimes imagined what life would be like if that small error were not there. A year ago, in December, he learned how a technology called CRISPR might make that possible. A scientist named Eric Olson had requested some of Dupree's blood a few months earlier, and Dupree had agreed. Soon he was rolling through the lab on his TiLite wheelchair so Olson, a biologist at the University of Texas Southwestern Medical Center, could show him the results—and what some scientists now predict is the likeliest way to cure Duchenne.

Using CRISPR, which makes it possible to snip DNA open at a precisely chosen spot, a team at the hospital had modified his cells in a dish, cutting through the extra exon. When DNA is broken this way, a cell races to make a repair, but the natural repair process typically makes a small error. This causes the unwanted genetic instructions to become unintelligible. The editing process required only a single step and had taken three days. In an image taken with a microscope, his cells were clouded with green puffs of perfect dystrophin.

"I try to be realistic with my expectations," says Dupree. "But that gave me a sense of 'Wow, this is here.'"

The potential to precisely and easily "edit" any genome using CRISPR is changing the way we think about nature. The CRISPR technique is often likened to a "search and replace" function for DNA. To laboratory scientists, it might better be compared to the discovery of fire. Every day they publish an average of eight scientific articles describing new uses of the technology—or merely reflecting on its exponentially expanding possibilities, like designer babies engineered with desirable traits and mosquitoes with DNA programmed to make them go extinct.

Among these possibilities, the chance to end the pain and suffering of people like Dupree is CRISPR's most compelling,

if still distant, promise. In early-stage lab experiments, academic scientists are showing that gene editing offers new ways to attack cancer, to knock out HIV and hepatitis infections, even to reverse blindness and deafness. Companies aren't far behind. Three startups in the Boston area have already raised a combined \$1 billion and partnered with some of the world's biggest drug companies, like Bayer and Novartis. "None of us can anticipate where this technology will end up," says Olson. "I'm operating under the premise that it will take us farther than we can imagine."

Scientists know the gene errors responsible for around 5,000 inherited disorders, and sequencing labs discover some 300 more each year. Some are one-in-a-billion syndromes. Duchenne is at the other extreme; it is one of the most common inherited disorders, affecting 1 in 4,000 boys. Girls are affected rarely, and to a lesser degree.

Gene editing could be a way to erase such diseases, with a one-time, permanent alteration of a person's DNA. It's a step beyond conventional gene therapy—the 30-year-old idea of inserting entire replacement genes into a person's cells, usually using a virus. That approach is impractical for some diseases. The gene for dystrophin, for instance, is too large to fit inside a virus, as CRISPR's DNA-snipping proteins can. And sometimes a faulty gene that's doing harm needs to be silenced, so adding a new one won't help. CRISPR's ability to delete and swap out genetic letters makes a huge new range of treatments possible. Some doctors are now calling CRISPR "gene therapy 2.0."

To be sure, even gene therapy 1.0 has yet to fully arrive. After 30 years of research, scientists are still learning how to use viruses to move genetic instructions into a living person's cells. Only two gene-replacement treatments for inherited disease have ever been approved, both in Europe. But Olson says he is convinced CRISPR is the most plausible way to stop Duchenne. Early this year, he showed he could repair mutations in mice with muscular dystrophy after sending viruses stuffed with CRISPR ingredients into their veins. "A mouse is not a boy, but we think we know exactly what needs to be done," says Olson. If it works, he adds, "this is a cure, not a treatment."

Olson says the very first human test of a CRISPR therapy in a patient with Duchenne could begin in two years, in what would be a small, exploratory clinical trial involving just a few boys. Working with Jerry Mendell of Nationwide Children's Hospital in Ohio, a center for gene-therapy studies, they expect to give the treatment to monkeys during the next 12 months, a prelude to human tests. The researchers will also be looking to see whether the CRISPR gene therapy has unexpected effects. Accidental edits are a particular concern.



Debbie Dupree and her son, Benjamin, 24, who has Duchenne muscular dystrophy. Ben has volunteered cells for gene-editing experiments.

“I try to be realistic ... But that gave me a sense of ‘Wow, this is here.’”

Dupree, who is following events in the lab, says he’s not expecting much for himself. He knows the studies could take years, and since his mutation is unique, he’d need a therapy tailored just for him. “I am more excited about the implications scientifically than any treatment for me,” he says. But his mother, Debbie Dupree, says chat boards and Facebook pages where parents gather are already alight with questions. “There is a lot of talk. People want to know when it will be available,” she says.

Duchenne patients and their families won’t be the only ones anxiously asking that question. Countless others facing deadly cancers or HIV, as well as sickle-cell anemia and numerous other genetic diseases, could soon be watching the fate of those CRISPR-altered cells in Olson’s lab. Are they the beginning of a new era of medicine or merely one more promising research result that will never make it out of the lab? In particular, researchers will need to solve the next challenge: safely and effectively editing DNA in cells throughout a human body, thus turning CRISPR from an invaluable lab tool into a medical cure.

Deleting diseases

CRISPR evolved inside bacteria, over billion-year time scales, as a form of immunity against viruses. Bacteria collect and store short snippets of DNA from viruses that have invaded them, spacing the segments out through their own genome in a pattern called clustered regularly interspaced short palindromic repeats—the term that gives CRISPR its acronym. When reinfected with one of these viruses, bacteria can create copies of these genetic snippets, which zip up letter for letter with the new virus’s DNA—signaling to a specialized cutting enzyme that it should attach itself and close, pincer-like, onto the viral genome and sever it.

By 2013, teams of scientists in Boston, Berkeley, and Seoul separately showed that this naturally occurring bacterial immune process could be simplified and repurposed to cut DNA in human cells. Though scientists had previously created gene-editing proteins, these were difficult to design and build compared with the solution bacteria had devised. “Instead of version 2 or version 3, it was version three trillion,” says Tom Barnes, chief scientist of the CRISPR startup Intel-lia Therapeutics in Cambridge, Massachusetts. “And it went from no labs working on it to everyone working on it.”

Intellia is one of a trio of startups that have set up shop around Boston and raised about \$300 million each to create CRISPR treatments; the others are Editas Medicine and CRISPR Therapeutics. Barnes says CRISPR vastly simplifies gene editing because of the way the cutting works. Just as bacteria spot and slice the viral genetic material, CRISPR can zero in on specific stretches of human DNA. The only ingredients needed are an editing enzyme—one named Cas9 is used most often—and a short “guide,” or length of genetic letters, to tell it where to cut.

It seems simple, but using it to create human treatments is anything but. And there’s one hitch that’s often overlooked: “editing” is a bit of a misnomer. Scientists have mastered cutting into DNA, which gives them something akin to a “delete” key for genes, in addition to the “add” function offered by traditional gene therapy. But they can’t as easily rewrite genes letter for letter, an aspect of the technology still being developed. For now, that mostly limits them to situations where deleting genes—or parts of them—is useful. Duchenne is one of those. Another is sickle-cell disease, a condition that in the United States affects mostly African-Americans. Medical researchers have given it relatively little attention in the past, but there’s an obvious DNA cut that might solve it, meaning a potentially elegant cure. Now Mitchell Weiss, a hematologist who treats people with sickle-cell at St. Jude Children’s Research Hospital in Memphis, says every gene-editing company is calling him. “The interest right now is incredible,” he says. “Before, no one was interested. No one cared. But they need a proof of principle, and this is a good one.”

In addition to finding the kind of genetic problem to which CRISPR offers a solution, companies need a



Eric Olson, an expert in genetic engineering at UT Southwestern, began using CRISPR three years ago to develop a treatment for muscular dystrophy.

“The interest right now is incredible. Before, no one was interested. No one cared.”

A Time Line of Genetic Modification

1971–’73: Development of recombinant DNA allows researchers to cut and paste genes in bacteria.

1978: A team at Genentech adds the human insulin gene to bacteria, launching the biotechnology industry.

1990: Physicians in Pennsylvania attempt gene therapy on a four-year-old girl. A gene is added to her body using a virus.

1999: Teenager Jesse Gelsinger is the first person to die in a gene-therapy experiment. Commercial interest slows dramatically.

2009: U.S. biotechnology firm Sangamo Biosciences initiates an effort to cure HIV with blood cells from which it has, for the first time, deleted a human gene.

2013: Scientists in the U.S. and South Korea demonstrate CRISPR as a new, much easier method of changing human genes. Editas Medicine is founded in Boston to develop CRISPR treatments.

way to get the CRISPR instructions into the body. Most are counting on viruses for that job, but Intellia's strategy is to package CRISPR into fatty blobs that liver cells suck up, just as if they were cholesterol. This August, at the annual CRISPR meeting in Cold Spring Harbor, New York, researchers from the company showed that with a single dose, they could alter the genomes of at least half the cells in a mouse's liver. If Intellia can successfully edit liver cells in a person, that may let the company treat a slew of previously unassailable metabolic conditions like a form of hereditary amyloidosis, in which painful plaques build up in the body.

What's obvious is that it will be easier to get CRISPR to work in some parts of the body than others. The easiest task is probably deleting genes in blood cells, since these cells can be removed from a patient and then put back. Already, a Chinese drug company has opened a study to create supercharged immune cells to battle cancer, and scientists at the University of Pennsylvania have announced similar plans with the financial backing of the billionaire Internet entrepreneur Sean Parker.

If you're looking for gene editing's Everest, it's probably rewriting DNA in the human brain—say, to treat Huntington's disease. Editing muscle cells lies somewhere in the middle of the difficulty scale. Genetically, it's a good candidate. Even with just a delete key, Olson says, up to 80 percent of muscular dystrophy cases could be cured in theory. Initially, the editing treatment he's working on will target a hot spot in the dystrophin gene—exon 51, in which Editas has also signaled an interest. Deleting that exon could treat about 13 percent of Duchenne cases.

The most significant unknown is whether it will be possible to edit enough muscle cells and make enough dystrophin in a human body. "I think this represents the most promising strategy," says Olson. "But the thing that has to go right is that it has to be efficient." Muscles, including the heart, glutes, and biceps, make up 40 percent of a person's body mass—billions

and billions of cells. So far, in his mice, Olson has succeeded in producing dystrophin in 5 to 25 percent of muscle fibers. It's half calculation and half speculation, but he thinks that editing 15 percent of the muscle cells in a boy will be enough to slow, if not halt, muscular dystrophy.

When I last spoke to Olson, he was rushing to a phone meeting to drum up commercial support for his idea of starting a human test for a Duchenne treatment. He's been talking with several companies, including Editas, probably the best-known of Boston's trio of CRISPR startups. It has Bill Gates and Google as investors. And the company, founded by several of the inventors of CRISPR technology, also declared an early interest in Duchenne, licensing work done at Duke University. But its chief operating officer, Sandra Glucksmann, said it isn't providing updates on the Duchenne program.

In fact, Editas has been lying low. CRISPR could potentially treat so many different diseases that the company has been reluctant to announce what its do-or-die project will be. And proving that any CRISPR drug is effective could easily take a decade. That puts Glucksmann in a tough position. On weekends she answers e-mails from desperate parents: "Could CRISPR cure my child?" In theory the answer may be yes, but about a quarter of the time Glucksmann has never even heard of the illness before. And the answer Editas has been giving to the parents of boys with muscular dystrophy has been particularly disappointing: "I am very sorry to hear about your son. Unfortunately, we are still in the very earliest stages of research."

Individual treatments

One thing that's already apparent is that many inherited genetic diseases will require tailoring a CRISPR treatment to very specific mutations—those affecting small subsets of patients or even individual people. Take Dupree, who lives less than a mile from Olson in a Dallas suburb. His mutation is unique, and it's not near exon 51, so he wouldn't be helped by the first CRISPR treatment that Olson is developing.

But there's no question in Olson's mind that Dupree's mutation is correctable too, given that the technique can potentially target any spot on the genome. Dupree now sees at least a glimmer of a chance that someone could make a CRISPR treatment just for him. "It's only given once, and maybe it's not that expensive," he says. "It made me think about how it could be done, because I see things moving closer."

At Toronto's Hospital for Sick Children, I met its pediatrician in chief, Ronald Cohn, who is also a muscular dystrophy doctor. Cohn is certain that with CRISPR one-of-a-kind

2014: Adding CRISPR to muscle cells in a lab dish, a team at Duke University eliminates a mutation that causes Duchenne muscular dystrophy.

2015: Chinese scientists edit the DNA of human embryos. Within months, the world's scientists condemn as "irresponsible" any attempt to make gene-edited babies.

2016: First human tests of CRISPR, as part of cancer treatments, win initial approval in the U.S. and China.

treatments are possible and even likely. Last December, he published a paper showing corrections of several rare mutations—again in cells in a lab dish, including some taken from a child with dwarfism and others from another boy with Duchenne. That boy, named Gavriel Rosenfeld, is the son of close friends of Cohn's in London. They run a charitable foundation that Cohn advises.

Cohn is a newcomer to CRISPR. A few years ago, he was studying hibernating squirrels. They don't move for months, yet their muscles aren't any worse for it. That is the sort of "we might just find something" approach favored in basic-research labs. Now, with gene editing, he sees a direct path to curing someone he knows. Gavriel is 14, and since correcting his cells, Cohn's lab has also created a mouse model that shares his mutation. Like Dupree's, the mutation is one of a kind, and within a few weeks Cohn's lab will start treating the mice.

But then what? Cohn says he doesn't know. How would you even test a drug designed for one person? Who would pay for it? He says he visited Health Canada, the country's regulator, and was told to come back if he cured the mice. "This is going to require a significant rethinking," he says. "And the fact that you and I are having this conversation is the beginning of the paradigm shift."

Cohn's approach of correcting individual mutations has stirred hopes among parents of boys with Duchenne. "This is a CURE!!!" one wrote on the Web. His lab has used CRISPR to fix mutations in cells taken from several boys he knows, and a waiting list he keeps in a spreadsheet currently lists 53 children with muscular dystrophy. The parents of all of them want to know if their child could be helped by gene editing.

If a gene-therapy study like the one Olson plans is successful, and if CRISPR reaches enough muscle cells, there might be a strong argument that a one-off treatment would work. After all, to aim at a new mutation all you'd do is tweak the component of CRISPR that zeroes in on a specific DNA sequence. The price of manufacturing a single dose also might not be an obstacle. Two existing gene therapies approved in Europe cost \$1 million and \$665,000. Even if it cost twice that, a one-time gene fix with CRISPR would be cheaper than a lifetime of costly drugs, wheelchairs, and dependency.

In holding out the hope of individual cures, Cohn admits he's created some new problems. He has invited parents to the lab, and little boys have tottered among the lab stools. But during a three-hour lab meeting this fall, he and his students decided to stop referring to "Gavriel's cells" or "Jake's cells" and use numerical code names instead. They still know who is who, but this gives them space to be impartial. "I know in the back of my head, but you want to stay unbiased," a graduate

student in the lab, Tatianna Wong, told me. "I can't work on this case just because I feel bad for him. I have scientific questions to answer."

High expectations

Some veterans of gene therapy roll their eyes when they hear what newcomers think CRISPR will do. I visited the vector development center at St. Jude, touring a cramped L-shaped lab with Byoung Ryu, an expert in making viruses, who chopped the air above his head and said, "People's expectations are up here." Ryu warns that basic, unresolved biological problems remain. One is whether editing will work often enough in cells such as those in the bone marrow, the type that need to be changed to correct sickle-cell disease. If too few cells end up edited, the treatments won't be effective. "It's a numbers game," says Ryu.

Ryu was the first employee at a Boston-area gene-therapy company, Bluebird Bio, whose stock price staggered down the chart after its first few patients didn't all respond the same way. "I'm not negative on CRISPR, but there is a reality check," Ryu says. "It's not coming to people next year. It works in the petri dish every single time, but my perspective is that genome editing may happen in the future but not in the near term."


CRISPR's future as a treatment depends heavily on the skills of gene therapists like Ryu. They've been making progress, yet so far, only two gene therapies—the kind that add an entire gene—have reached the market to address an inherited disorder. One, called Strimvelis, provides an outright cure for a fatal immune deficiency and was approved this year in Europe. But it took 15 years to test it on 18 children, and similar trials had failed. "What I learned about gene therapy is that the rabbit does not win the race. The tortoise wins the race," says Weiss, who leads the St. Jude effort to apply gene editing to sickle-cell disease.

Side effects could also be an obstacle. CRISPR has the potential to cause accidental, unwanted edits that could not be erased if they ended up written into a person's genome. Currently, researchers rely on academic computer programs to predict such effects. (One, maintained at Harvard, is called CHOPCHOP.) But a program can't predict everything. Two early tests of gene therapy, in the 2000s, accidentally caused leukemia in several children. No one had anticipated that consequence of changing the genome. Although Olson says he has not seen ill effects in his mice, he allows that CRISPR can cause "inadvertent changes in DNA that are important for life." And editing billions of individual cells in a person's body, scientists acknowledge, will be the surest way to discover how CRISPR can go wrong.



Boys with muscular dystrophy demand action on new drugs during a 2016 meeting at the U.S. Food and Drug Administration.

“What I learned about gene therapy is that the rabbit does not win the race. The tortoise wins the race.”

It may take a lot longer than we think, but sooner or later gene editing will change what medicine looks like. The biotechnology industry began in the 1970s when someone grafted insulin into *E. coli*, showing that a human protein could be manufactured outside the body. Now there’s a way to change DNA where it lies, inside your genes. When he looked through a microscope at his own cells in Olson’s lab, Dupree tried to take the rational view: here was a solution for the next generation of boys. His mother, however, has allowed herself to hope. “I was ecstatic. I remember thinking, ‘This could be something that works,’” Debbie says. Duchenne is a ticking clock. Parents can’t help making the calculations: this long for animal studies, this many years for the first human trial, that much more time until they know if it really works. Luckily, Ben’s disease is the slow-moving kind. The doctors said he’d be gone by 19, but he’s still here. And maybe he’ll still be here in 10 years, says his mother, “so they can try it on him.” 

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HEADS UP: BLAST GAUGE OFFERS IMPROVED WAY TO IDENTIFY SOLDIERS AT RISK FOR TRAUMATIC BRAIN INJURY

Traumatic brain injuries (TBIs)—often a problem for military personnel, due to their frequent exposure to blasts—have long stumped medical researchers, neurologists, and other clinicians.

Unlike other injuries, TBIs often have no immediate symptoms, so they can go undetected until it's too late for them to be treated effectively. But if medical personnel could better detect when soldiers have been subjected to potentially damaging shockwaves, they might be able to limit further exposure and decrease the soldiers' risk of developing TBIs.

Today, a wearable device created from a collaborative effort between Analog Devices, Inc. (ADI) and BlackBox Biometrics is providing real-time data on blast effects. The Blast Gauge System measures exposures that could put soldiers (and others) at risk for a TBI long before its physical and cognitive symptoms surface.

Blast Gauge can quickly and accurately indicate when, and how severely, soldiers have been exposed to harmful shockwaves. That information helps medical personnel determine whether and when soldiers should return to the field—and helps reduce their risk for TBIs.

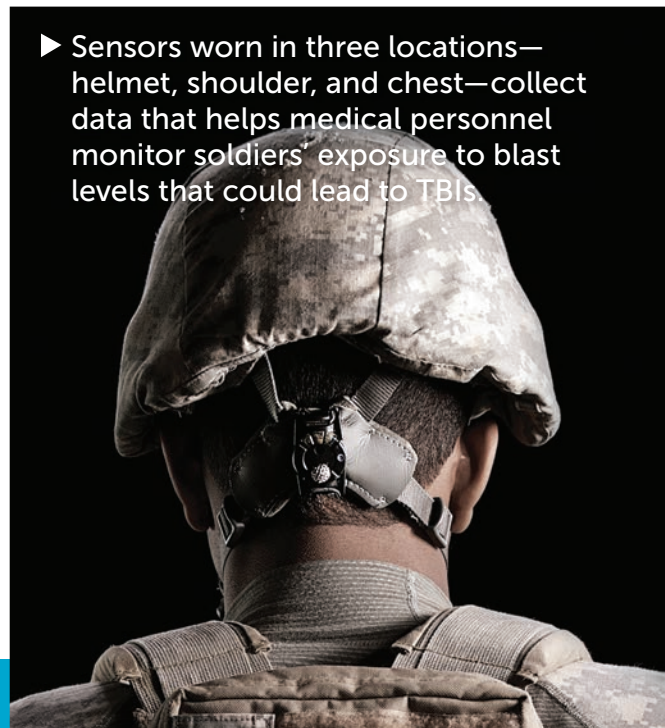
Better Detecting Wartime's 'Signature Wounds'

TBIs are often called the "signature wounds" for soldiers stationed in Iraq and Afghanistan because of the pervasive use of improvised explosive devices (IEDs) by enemy forces in those countries. According to the Defense Medical Military System, nearly 348,000 active U.S. military personnel suffered TBIs between 2000 and the first quarter of 2016. However, these numbers don't include the growing number of veterans diagnosed with TBIs years after their initial exposure to battlefield blasts.

Large explosions aren't the only threat, however; multiple smaller hits can also cause brain injuries. For example, "breachers"—soldiers who knock down doors and other obstacles, often using explosives—are routinely exposed to smaller blasts. "Recent research has shown that our service members are subjected to really significant repetitive blast exposures," explains BlackBox Biometrics founder and CTO David Borkholder. BlackBox Biometrics developed Blast Gauge with assistance from ADI, whose technology contributed significantly to the device's design and engineering.

Founded in 2011, BlackBox Biometrics focuses on developing wearable devices that measure blast "overpressure," the rapid pressure change and multiple shockwaves generated by IEDs, artillery, shoulder-fired rockets, and explosives.

► Sensors worn in three locations—helmet, shoulder, and chest—collect data that helps medical personnel monitor soldiers' exposure to blast levels that could lead to TBIs.





► A Blast Gauge sensor glows red, indicating exposure to potentially harmful blast shockwaves.

Blast Gauge began as a collaborative effort among Borkholder's team at the Rochester Institute of Technology, the Defense Advanced Research Projects Agency (DARPA), and ADI. Today, the device is used by more than 500,000 special-operations military forces from the United States, Canada, Australia, and the European Union, as well as by the FBI and police departments' special weapons and tactics, or SWAT, teams.

Blast Gauge consists of three ruggedized sensors that soldiers wear on their helmets, chests, and shoulders. Each includes an ultra-low-power microelectromechanical systems (MEMS) inertial sensor that captures blast magnitude and acceleration force. Blast Gauge uses the sensors' data to measure the blast impact, says Wayne Meyer, MEMS sensor strategic marketing manager at ADI, who has long collaborated with Borkholder on the Blast Gauge project.

In September 2016, BlackBox Biometrics rolled out its next-generation Blast Gauge. The new version includes a low-power accelerometer designed by ADI that dramatically increases the device's battery life.

It also allows medical personnel to wirelessly collect blast-impact data and make immediate decisions based on their findings. Previously, soldiers used USB ports to manually download Blast Gauge data to computers, delaying medics' access to critical information.

Long-Time Collaborators

ADI and Borkholder have been working together since 2009, when DARPA granted Borkholder \$1 million to develop what eventually became Blast Gauge. With ADI's help, BlackBox Biometrics met an aggressive military deadline, deploying 1,000 units to soldiers in Afghanistan in just 11 months. BlackBox Biometrics needed an ultra-low-power high-G inertial sensor to use with military personnel. ADI's

technology helps Blast Gauge devices capture data about the impact of a blast on individual soldiers—an impact that often measures between 60 and 120 times the force of gravity, ADI's Meyer explains. ADI was the ideal partner for providing that capability because of its expertise in MEMS sensor technologies, Borkholder says, adding that ADI also achieved the first-time integration of three high-performance sensors in one low-power, wearable, ruggedized device.

ADI continues to be instrumental in helping BlackBox Biometrics develop additional generations of Blast Gauge, Borkholder says. "The battery life of the very first Blast Gauge prototype was only about one month. Now, thanks in large part to ADI's low-power technologies, batteries can last up to a year." That makes a big difference to soldiers in the field, Meyer notes: "When our system is deployed, they don't have to recharge it—which is really important."

Borkholder predicts that data from the use of increasingly sensitive devices will reveal the development of long-term neurological disorders from "repetitive sub-concussive hits," which are experienced not only by soldiers, but by athletes and industrial workers as well. ADI and BlackBox Biometrics have collaborated on Linx IAS, technology designed to help coaches, parents, and managers share crucial information with medical professionals to more accurately triage and treat head injuries.

Meanwhile, Meyer says, ADI and BlackBox Biometrics engineers regularly exchange ideas not only for new iterations of Blast Gauge, but for other products as well. That means that plenty of groundbreaking developments are likely just over the horizon.

To learn more about the collaborative work of Analog Devices, Inc. and BlackBox Biometrics, visit analog.com or blastgauge.com/about.

Reviews



Restoring the Allure of the Movie Theater

Filmmaker Douglas Trumbull has invented a super-immersive film format and projection technology in hopes of improving the cinematic experience. Now he needs to get the industry to pay attention.

By Elizabeth Woyke
Photographs by Leonard Greco

In a tiny private theater in the Berkshire Hills of Massachusetts, filmmaker Douglas Trumbull is screening one of his latest creations. At first, the movie looks familiar: it's footage of astronaut Chris Hadfield singing David Bowie's "Space Oddity" in a clip that went viral on YouTube a couple of years ago. But halfway through the song, the film shifts from Hadfield strumming his guitar in the

International Space Station to 3-D shots of planets and stars so detailed that I feel as though I'm on the ISS itself, looking through its cupola windows. A huge image of Earth fills my field of view and begins rotating. I'm wearing 3-D glasses, but the picture is far brighter and sharper than is typical in 3-D movies. Next to me, people mumble things like "Completely unreal" and "Awesome."

This is Magi, a system that captures images in 3-D and “4K” ultrahigh resolution and displays the resulting frames at five times the usual rate. Trumbull developed the technology as a way to create movie experiences more immersive than regular 3-D or giant-screen IMAX—and restore the joy of going out to the movies.

Trumbull, 74, has spent his entire life thinking about how people experience the illusions of cinema. He grew up in Los Angeles fascinated by the Cinemascope widescreen movie format; got his first Hollywood job, doing visual effects for *2001: A Space Odyssey*, in his 20s; and went on to direct two cult-classic films (*Brainstorm* and *Silent Running*) and design visual effects for *Blade Runner*, *Close Encounters of the Third Kind*, and *Star Trek: The Motion Picture*. Now, in an age when the movie theater is losing its allure, he’s hoping to wow people yet again—this time using Magi’s “hyper-reality,” which enables audiences to connect intensely with stories and vividly experience a character’s perspective.

Magi isn’t suitable for all movies, just as 3-D isn’t appropriate for intimate dramas and many other conventional films. But Trumbull hopes filmmakers will use Magi when they want viewers to feel awestruck in a highly sensory way, as I did upon seeing shots of Earth in Trumbull’s space-station demo movie. “What interests me is being able to create profound personal experiences for audiences,” Trumbull says. “Whatever it is, I want you to feel like what’s happening on the screen is actually happening in real time, to you, in this theater.”

The movie industry could use some magic. North American box office receipts have been relatively flat for years. Many consumers prefer the convenience and affordability of watching movies on their TVs and mobile devices, especially since

manufacturers keep developing sharper, brighter, more color-accurate screens.

To develop something far better, Trumbull built a studio on his sprawling Berkshires property; hired a multitasking crew that ranges from four to 50 people, depending on the project; and produced a series of demos that tested new cinematic

techniques, such as how to combine different frame rates and resolution levels in one movie. On top of all

that, he has created a new type of movie theater optimized for showing Magi films.

His self-sufficient approach means Trumbull can have an idea in the morning, shoot it in the afternoon, and view it on a screen by evening. Going it alone suits his personality, but he admits that his quest has been frustrating at times. “I really like the excitement of the exploration, but I’ve spent many years of my life trying to make this happen and also feel like I’m a fish out of water in the sense that I’m having to pay for and do all of these experiments myself,” he says.

But Trumbull isn’t alone in his obsession with using such techniques to improve the moviegoing experience. Director Ang Lee shot part of his latest film, *Billy Lynn’s Long Half-time Walk*, using a similar process, combining 3-D, 4K resolution, and ultrahigh frame rates. Lee’s drama about American soldiers returning home after fighting in Iraq attracted early praise ahead of its November opening and should lend legitimacy to this still-experimental technology.

Outdated standards

Most movies today are shot at 24 frames per second (fps): in the course of every second, the projector shows 24 still

images. The standard was established in the 1920s, largely to sync film images with soundtracks, and is ill suited to action movies, where it can cause blurriness because the camera’s shutter is open too long to keep up with the fast motion.

Motion blur is particularly bothersome in 3-D movies, because most digital cinema projectors show 3-D by quickly switching between images meant for the left and right eyes to create the illusion of depth. Blur makes it difficult for our visual systems to fuse the images, which can cause eyestrain, according to Tim J. Smith, a visual scientist at Birkbeck, University of London.

At higher speeds, however, the mind isn’t distracted by the stitched-together effect. After years of analysis, Trumbull thinks 120 fps is the optimal projection speed for digital 3-D movies. To make Magi movies, he uses two cameras or two sensors in one camera, and he photographs the left- and right-eye images at a slight offset instead of simultaneously, which is how conventional 3-D movies are made. Because one of the two camera shutters is open at any given moment, the Magi process captures all the action instead of just half of it.

Trumbull then projects the movies in the same way they were shot—alternating left and right frames at 60 fps per eye—for a result that looks incredibly realistic.

A few other directors similarly believe that high frame rates can pull audiences more deeply into their movies. James Cameron has said he intends to use 48 or 60 fps for his *Avatar* sequels, the first of which is expected to be released in 2018. Between 2012 and 2014 Peter Jackson released 48-fps versions of all three of his *Hobbit* films.

Magi process, Magi Pod
Trumbull Studios



The interior of
Trumbull's Magi
Pod theater.



Some critics and viewers complained that Jackson's footage was so crisp it looked more like high-definition TV than a movie, exposing flaws in the sets, props, and actors' makeup. But Trumbull thinks he can avoid that problem by staying away from standard TV rates, which are roughly equivalent to 30 to 60 fps. Pushing the projection rate far higher, when combined with the other aspects of the Magi process, yields a completely new cinematic experience that he likes to compare to the holodeck from *Star Trek*—a place where you can essentially inhabit a made-up space and “what you see seems to be real.”

You have to see the Magi effect to understand it, so Trumbull plans to invite directors to the Berkshires to view his demo movies. In 2014, Ang Lee trekked to the 50-acre compound, where cell-phone reception drops out long before you reach the secluded driveway. Trumbull's main studio resembles a two-story barn, or maybe it just seems like one because the area is a working farm and chickens, donkeys, and goats roam freely in the rolling meadows nearby. It's currently being reorganized, but when Lee visited, it housed a green-screen stage and screening room, as well as offices and a small kitchen. Afterward, Lee decided to film *Billy Lynn* in 120 fps, which he said allowed him to foster “emotion and intensity” in unique ways.

Shooting movies at higher frame rates can be complicated because it generates huge amounts of image data, which is best stored on high-capacity solid-state drives and necessitates additional computing power when rendering visual effects with computer-generated imagery (CGI). However, Trumbull says those expenses would probably add up to less than 1 percent of a typical movie's total cost.

The greater challenge is getting theaters to exhibit these movies the way the

Trumbull inside a
green-screen studio
he is building on his
Berkshires property.



01



02



directors want. Many theaters upgraded their projectors to show the *Hobbit* movies, but only about half of theaters globally can play 3-D movies at 120 fps, which is the speed Trumbull has specified for Magi movies. What's more, those theaters would have to exhibit Magi films at a lower resolution than Trumbull intended, in part because studios impose limitations on cinematic projectors for what they describe as quality control reasons and have yet to release a standard for this movie format.

Magi Pods

Trumbull's solution is to build his own theaters. He has spent the past year crafting an oval-shaped, prefabricated mini-theater called a "Magi Pod," big enough for 60 people, that could be shipped to

multiplex cinemas and other facilities and assembled by a handful of people in a week.

Every aspect of the Magi Pod is meant to amplify the immersive nature of the Magi experience. The theater is deliberately small (1,300 square feet), to reduce audience eyestrain. Rows are laid out to ensure that each seat faces the center of the 36-foot-wide, 17-foot-tall screen, which offers a field of view twice that afforded by a regular movie screen. Because the screen is curved, to act as a lens focusing the light emitted by the projector, images appear three times brighter than the industry standard. Trumbull also included a 32-channel surround-sound system for more realistic audio effects and put special insulation inside the walls to eliminate reverberation.

01. A helmet used in Trumbull's 1983 movie *Brainstorm*, which depicted characters transferring their thoughts and emotions to each other via virtual-reality-type headsets.

02. One of Trumbull's Academy Awards. He won one in 1992 for inventing Showscan, an immersive high-frame-rate film process he developed in the 1970s and '80s, and another in 2011 for "technological contributions" to the motion picture industry.

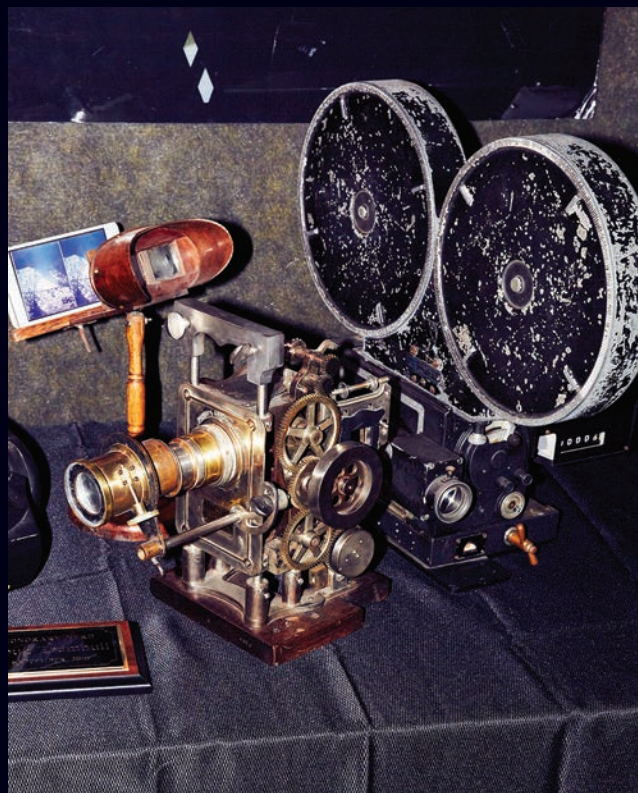
03. A model of the DeLorean time machine from *Back to the Future*, which Trumbull turned into a ride at Universal Studios.

04. An early 1900s hand-cranked "Cameragraph" projector from the Nicholas Power Company, which Trumbull keeps in his studio.

03



04



The pod might solve several problems for the movie industry by helping to ensure that the theater experience far exceeds what's possible at home. But if theater owners, who say they have already spent more than \$3 billion on new technology in recent years, pass on the idea, Trumbull will market it to other venues, including theme parks, zoos, aquariums, planetariums, national parks, and historic landmarks. And if Trumbull fails to reinvent the cinema, he's got other plans for the technology. One idea is to make Magi movies whose stories and characters can also play out in virtual- and augmented-reality headsets. He recently joined the advisory board of Magic Leap and has been mulling how to create content that would begin in Magi Pods and then live on in the startup's "mixed reality" device.

But Trumbull doesn't relish a future hawking Magi products. His goal is to find investors who share his passion for movies and will help commercialize the technology. What he ultimately wants is to return to making feature-length films, this time using the Magi process. He has already selected his next project: a space epic about "man's place in the universe" that will "pick up where *2001* left off," in terms of image and exhibition quality.

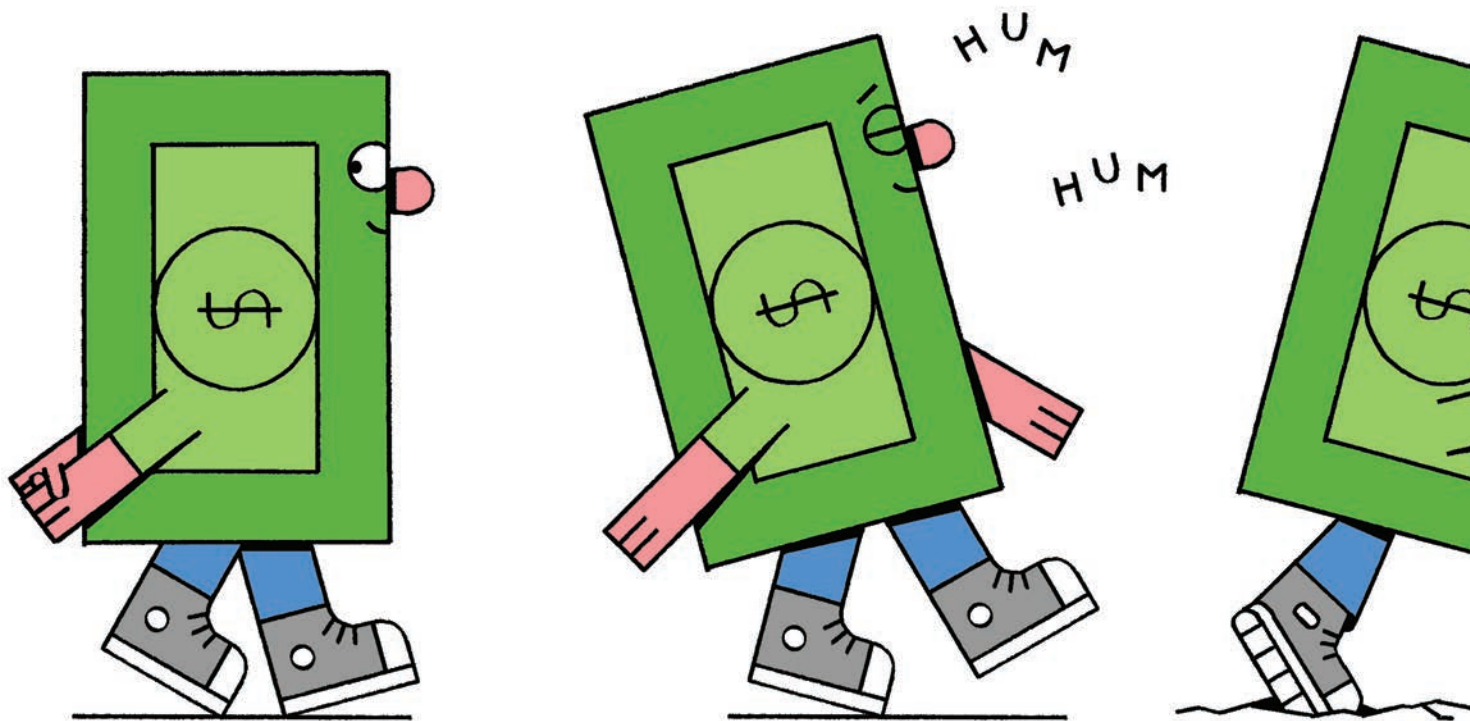
In fact, Trumbull says, his desire to advance cinema technology largely stems from his experience watching Stanley Kubrick use extreme wide-angle lenses and huge screens to compose scenes that made the audience experience the feeling of going into space and encountering the unknown. "Part of my quest has been trying to get back to something that's as

good as *2001*," he says. "I think it represented an apex in movie quality that hasn't been achieved since."

More than 50 years after Trumbull started working in movies, the idea of transporting people to alternate worlds continues to drive him. It's why he's expanding the studio on his property to include a new green-screen stage and a miniature props photography room at a time when he could be excused for retiring. The additions will enable him to produce his space epic in his backyard, using virtual sets.

"People want something different from everyday reality," he says. "My job is to get you there in a nontoxic way."

Elizabeth Woyke is business editor at MIT Technology Review.

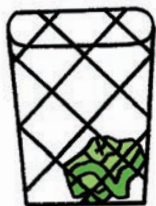


Capitalism Behaving Badly

It's time to rethink the role that government plays in shaping and supporting policies to solve big problems like climate change and income inequality.

By David Rotman

Despite healthy corporate earnings, an employment rate that has slowly rebounded since the financial crisis of 2008, and the outpouring of high-tech distractions from Silicon Valley, many people have an aching sense that there is something deeply wrong with the economy. Slow productivity growth is stunting their financial opportunities; high levels of income inequality in the United States and Europe are fueling public outrage and frustration in those left behind, leading to unprecedentedly angry politics; and yet despite the obvious symptoms, economists and other policy makers have been largely befuddled in explaining



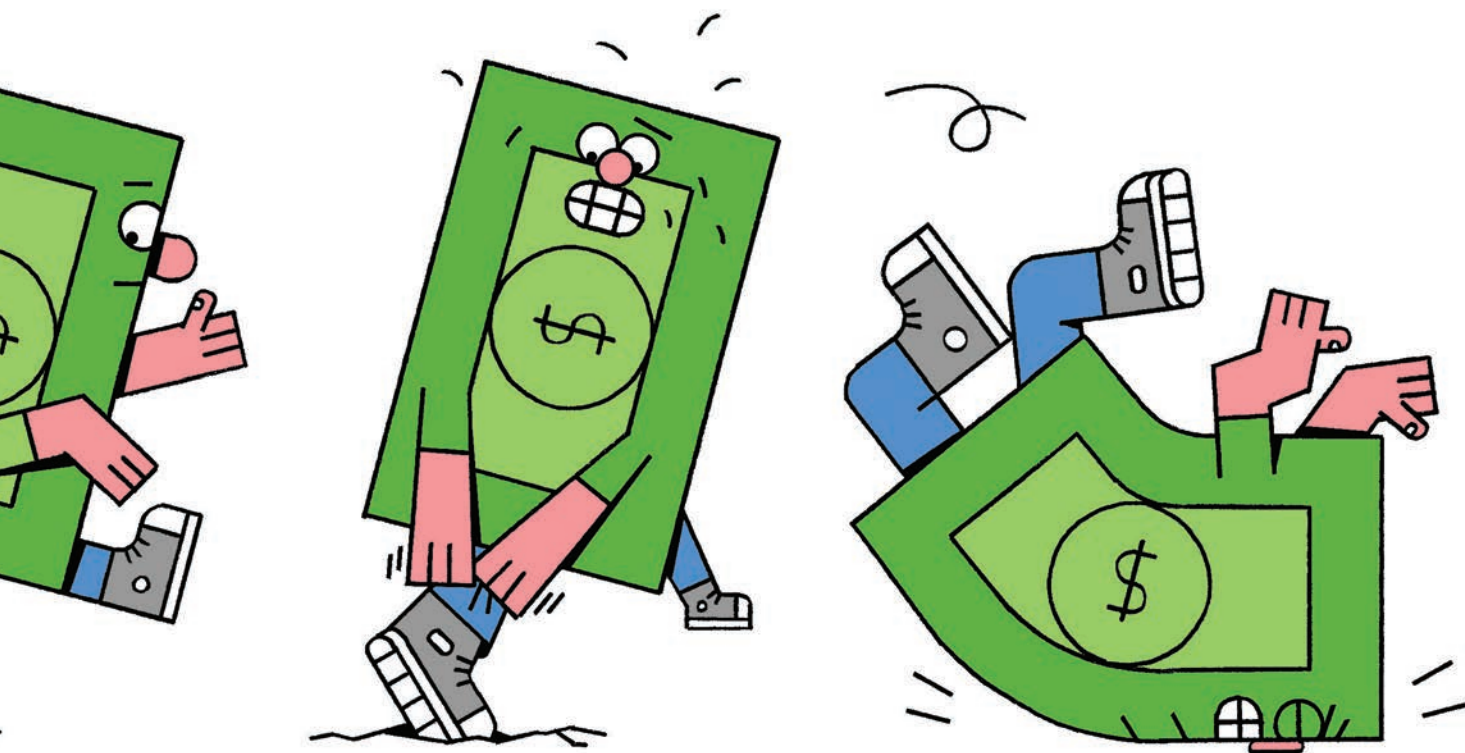
the causes and, even more important, the cures for these problems.

That's the starting point for *Rethinking Capitalism*. A series of essays by authors including Joseph Stiglitz, an economist at Columbia University who won a Nobel Prize in 2001, and Mariana Mazzucato, a professor of the economics of innovation at the University of Sussex and a rising voice in British politics, the book attempts to provide, as explained in its introduction, "a much better understanding of how modern capitalism works—and why in key ways it now doesn't." Together, the essays provide a compelling argument that we need more

coherent and deliberate strategic planning in tackling our economic problems, especially in finding more effective ways to reduce greenhouse-gas emissions.

In particular, Mazzucato, who also co-edited the book and co-wrote an introduction with Michael Jacobs, wants to counter the view that free markets inevitably lead to desirable outcomes and that freer markets are always better: the faith that "the 'invisible hand' of the market knows best." In fact, she argues, we should admit that markets are created and shaped by government policies, including government support of innovation.

There is nothing too contentious in that statement, but she extends the argument in a way that *is* controversial. Not



only is it the responsibility of governments to facilitate innovation, which she calls “the driving force behind economic growth and development,” but the state should also set its direction; the trajectory of innovation needs to be guided by policies to solve specific problems, whether the aim is increasing productivity or creating a green-energy transition. Mazzucato writes that innovation needs both “well-funded public research and development institutions and strong industrial policies.”

Industrial policies—or what Mazzucato sometimes calls mission-oriented public policies—have a long and divisive history. Economists define industrial policy in a very specific way: it’s when governments set out to play a deliberate role in directing innovation and growth to achieve a desired objective. Her call for the revival of such policies counters the idea that has held sway for decades among many politicians, particularly in the United States and the U.K., that government is better off not trying to

assert a role in steering innovation. She writes that governments should not only try to “level the playing field, as orthodox view would allow.” Rather, “they can help *tilt* the playing field towards the achievement of publicly chosen goals.”

For them to do so, Mazzucato said in a recent interview, “the whole framework needs to change.” The belief that the government should only intervene to “fix” the market in extreme circumstances, rather than acting as a partner in creating and shaping markets, means we’re constantly putting “bandages” on problems and “nothing changes.” The intractability of today’s slow growth and widening inequality can be traced, she says, to the fact that governments in the U.S. and Europe have increasingly shied away from their responsibilities. “We have to admit that policy steers innovation and growth, and so the question is where do we want to steer them?”



One of Mazzucato’s more controversial claims is that the private sector gets too much credit—and too many riches—for some of today’s most popular technologies. The iPhone, she contends, relied on advances, including the touch screen, Siri, GPS, and the Internet, that were all developed by state-funded research. Maybe. At times, she clearly takes this argument too far. Take, for example, her assertion that nanotechnology was initially funded by government initiatives and that the private sector jumped in later. In fact, key early inventions were made by IBM at its Zurich lab; these allowed researchers to image and manipulate single atoms for the first time.

Regardless, Mazzucato’s argument has resonated among many of today’s policy makers. After Theresa May took over as the U.K.’s prime minister this summer, Mazzucato was summoned to Downing Street. Change was clearly in the air. A few weeks earlier, May had announced a

newly formed Department for Business, Energy and Industrial Strategy. More than 30 years after Margaret Thatcher effectively killed off industrial policy in the country, another conservative prime minister was hinting at its revival. While it's too early to know the outcome, Mazzucato says, "It seems superficially encouraging."

Flying white elephants

The debate over industrial policies played out in the United States and the U.K. in the early 1980s as President Reagan and Prime Minister Thatcher preached the power of free markets and the dangers of government meddling. And for at least the next few decades, the free-market rhetoric clearly won out, as popular wisdom held that such interventions are tantamount to governments picking winners and losers.

Even advocates of industrial policies acknowledge that they have had a checkered history. In "Green Industrial Policy," Dani Rodrik, an economist at Harvard's John F. Kennedy School of Government, argues that such a strategy is needed to make the sweeping changes required to slow climate change. But he notes that executing industrial policies fairly has been a challenge. While such policies have "undoubtedly worked" in Japan, South Korea, China, and other countries, Rodrik writes, they have a reputation for being gamed in many countries by both businesses and political leaders. And industrial policies to support desirable sectors have given birth to such white elephants as the Concorde, a plane meant to bolster the aerospace industry in the U.K. and France.

Rethinking Capitalism: Economics and Policy for Sustainable and Inclusive Growth

Edited by Michael Jacobs and Mariana Mazzucato
Wiley-Blackwell
2016

"Green Industrial Policy"

Dani Rodrik
Oxford Review of Economic Policy
Vol. 30, No. 3, 2014

"Green" Growth and the New Industrial Revolution"

Alex Bowen, Chris Duffy, and Sam Fankhauser
Grantham Research Institute
January 2016

American Recovery and Reinvestment Act

February 2009

Because of this history, he writes, "economists traditionally exhibit scepticism—if not outright hostility—towards industrial policies." But despite the challenge of making them work, he argues,

industrial policies "have an indispensable role in putting the global economy on a green growth path," because markets have failed to properly account for the social cost of carbon dioxide emissions and the true technological benefits of risky energy R&D.

Rodrik said in an interview that while "unfortunately" we're stuck with the label "industrial policy," today's versions are very different from ones conceived decades ago. Rather than singling out a specific sector—say, aerospace or steel manufacturing—for support with large investments and tax incentives, new thinking suggests working across sectors to achieve a desired

goal such as addressing climate change, using tools such as carbon pricing. "It's really just pushing markets in a direction they wouldn't otherwise go," he says. "The idea is to get government working closely with businesses to achieve more rapid and appropriate growth."

In that sense, says Rodrik, it is something that governments have been doing all along, even as industrial policy fell out of fashion in the 1980s. However, one consequence of attempting to "fly under the radar" is that governments are often not explicit about their objectives, he says. "If the goal is to spawn new technologies in clean energy, let's say that." And, he says, "being more self-conscious and open provides a big advantage in designing better policies." Included in such designs

should be well-defined rules and procedures, insulating decision making from political whims and interests.

Take, for example, the failure of the solar company Solyndra. It is often held up as the kind of thing that occurs when government picks winners. But, writes Rodrik, Solyndra failed largely because competing technologies got much cheaper. Such outcomes are not necessarily an indictment of industrial policies. The real problem, Rodrik argues: the U.S. Department of Energy loan guarantee program that supported the solar company had a mixed set of goals, from creating jobs to competing with China to helping fund new energy technologies. What's more, it did not properly define procedures for evaluating the progress of potential loan recipients and, importantly, terminating support to those companies when appropriate. Instead, according to Rodrik, in the absence of such rules, money was lent to Solyndra for political reasons—President Obama and his administration used the company as a high-profile way to highlight its green-energy initiatives. Having singled out the solar company for praise, the administration was then reluctant to end its commitment.

Pork-barrel politics

President Obama's eight years in office will be judged in part on the \$787 billion stimulus bill that passed in 2009 and included some \$60 billion for energy projects and research. In some ways its results, both positive and negative, present a valuable lesson on just how difficult it is to put economic theory about industrial policy into practice.

The stimulus bill was well-intentioned, and the instinct to use government spending for a specific social goal, supporting the development of green energy, was laudable. The investment in energy was badly needed. But from the start, the energy spending was headed for trouble because it tried to serve multiple purposes: provide



a monetary boost, create jobs, and seed the beginning of a green-energy infrastructure. As a leading economist warned in these pages: “It’s very much like pork-barrel politics.” (See “Can Technology Save the Economy?” May/June 2009.)

The problem was that those objectives often conflicted. Stimulating the economy meant spending money as quickly as possible, while investing wisely in energy projects required deliberate decisions and rigorous due diligence, both of which take time.

What’s more, investments were made to help economically stressed regions even if they weren’t the wisest choices for building an energy sector. Government investments were made in a number of large battery production facilities in Michigan, each one coming with a promise to boost the local economy, even though there was not yet nearly enough demand for the batteries. Among the outcomes of the stimulus investments, not surprisingly, were the bankruptcies of Solyndra and other solar and battery startups.

The stimulus energy investments were “a bit of a disaster,” says Josh Lerner, a professor at Harvard Business School. “A lot of the problem was in the ways they were implemented. They violated all the rules of how these things should be done.” Not only did the government make large bets on a few companies, in effect picking winners, but it did so without clear rules and criteria for the choices. And, says Lerner, “the selection of the battery and solar companies was extremely opaque. A lot of it seemingly came down to if you had a former assistant secretary of energy doing the lobbying for you.”

Still, Lerner is not dismissive of government interventions to support green-energy innovation. “You can make the case that the need is greater than ever. A well-designed program would potentially make a lot of sense at this point.” But, he

says, “experience tells us there are more misses than hits” with such government interventions. And he suggests that such programs often fail because their creators are not familiar enough with any given technology and its business. “The decisions might seem plausible, but they turn out to be unproductive. The devil is in the details.”

Even some of the stimulus’s greatest apparent successes now seem to be less effective than originally hoped.

Steven Chu, a Nobel Prize-winning physicist, was named secretary of the Department of Energy in

early 2009 and implemented many of the bill’s most ambitious efforts to boost energy R&D. It funded large increases in energy research, and Chu created a series of well-conceived centers and initiatives, including the Joint Center for Artificial Photosynthesis and ARPA-E, a program to support early-stage energy technologies. But in subsequent years, budget cutbacks and political pressure took their toll on these projects, which needed patience and consistent funding. As a result, ambitious research and technology initiatives are now ghosts of their once high-profile selves.

The outcome makes one wonder just how such policy initiatives, which include investments in research and engineering projects that require years to bear fruit, will ever survive the constantly changing political moods and government leadership. Creating a rigorous industrial policy to encourage green technologies is no doubt a worthwhile objective. Economists and the lessons from efforts like the stimulus bill can teach us how to design such policies to be robust and effective.

But won’t wise industrial policies also require wise politicians?

David Rotman is MIT Technology Review’s editor.



Events

Harvest Summit

November 4, 2016
Sonoma County, CA
harvestsummit.com

EmTech Asia

February 14–16, 2017
Singapore
emtechasia.com

EmTech India

March 9–10, 2017
New Delhi, India
emtech.livemint.com

SXSW Interactive Festival

March 10–14, 2017
Austin, TX
sxsw.com/festivals/interactive

EmTech Digital

March 27–28, 2017
San Francisco
events.technologyreview.com/emtech/digital/17

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Mark Zuckerberg's Long March to China

The Chinese government likes to control social media and what people do with it—but Facebook looks willing to launch in China anyway.

By Emily Parker

For U.S. Internet businesses, China is the land of moral defeat. Many people hoped that Western technology companies would loosen China's control over information. Instead, those companies have willingly participated in efforts to censor citizens' speech. Yahoo gave Chinese authorities information about democracy activists, landing them in jail. Microsoft shut down the blog of prominent media-freedom activist Michael Anti. Google censored search results that were politically sensitive in China. In 2006, those three companies came before Congress and were accused by a subcommittee chairman of "sickening collaboration" with the Chinese government. Google shut down its mainland Chinese search engine in 2010, publicly complaining about censorship and cybersecurity.

Facebook has been blocked in China since 2009, and its Instagram photo-sharing service was blocked in 2014. I once thought that it would be disastrous or impossible for the social network to try a Chinese adventure of its own, and some China experts still believe that to be true. But a Facebook launch in China now looks probable.

Facebook's founder and CEO, Mark Zuckerberg, has signaled to Beijing that he's willing to do what it takes to get into the country. People who know the company well think it will happen. "It's not an if, it's a when," says Tim Sparapani, who was Facebook's first director of public policy and is now principal at SPQR Strategies, a consulting firm. Facebook declined to comment for this article, but Zuckerberg said last year: "You can't have a mission to want to connect everyone in the world and leave out the biggest country."

A decade after Google's hopeful but ill-fated entry into China, U.S. Internet companies may see the Chinese market as even more tantalizing—yet impenetrable. The number of Chinese Internet users

has surged to some 700 million, and they represent a valuable untapped resource for American companies with saturated, highly competitive home markets. But the Communist Party's attempts to control information have also grown more intense. In addition to the "Great Firewall" that blocks access to foreign websites, legions of human censors, many employed at Internet companies, police domestic blogs and social networks. And a U.S. company would now have to compete with China's own Internet giants. WeChat, a messaging app from the behemoth Tencent, has

Zuckerberg clearly thinks China is worth the trouble, even if that means leaving some "Western values" at the door. Earlier this year, he traveled to Beijing and had a high-profile meeting with China's propaganda chief, Liu Yunshan. Chinese state media reported that Facebook's founder praised China's Internet progress and pledged to work with the government to create a better cyberspace. Liu highlighted the notion of Internet governance "with Chinese characteristics." The translation was clear: a Chinese version of Facebook would definitely be censored. This year's trip was something of a sequel. In 2014, he hosted Lu Wei, minister of the Cyberspace Administration of China, at Facebook's offices. President Xi Jinping's book *The Governance of China* just happened to be on Zuckerberg's desk.

This courtship hasn't been without some awkward moments. When Zuckerberg posted a photo of himself cheerfully jogging through the polluted haze of Tiananmen Square this year, he was mocked on Chinese social media. But overall he has made the right moves, says Cheng Li, director of the John L. Thornton China Center at the Brookings Institution. "Chinese leaders pay a lot of attention to personal relationships,"

he says. "They think Mark Zuckerberg is a friend of China. He's successful. He's very China-friendly. He has a Chinese wife. He speaks Chinese. So what else do you want?"

At your service

Facebook will still have to overcome Beijing's suspicions that American Internet companies could destabilize the Communist Party's rule. Media outlets that described the Arab Spring as the "Facebook Revolution" didn't do the company any favors. And documents leaked by the former intelligence contractor Edward Snowden fueled Chinese suspicions that American technology companies had "back doors" for U.S. government surveillance.

But Facebook's potential to help Chinese businesses go global could lead Beijing to see the company as a net positive. It already sells advertisements to Chinese companies for display outside the country, but launching a version of Facebook in China could strengthen the connections between Chinese companies and overseas customers.

The fact that China now has mature social-media companies of its own might also make the government less wary of Facebook. The company would be unlikely to displace incumbents such as the ubiquitous WeChat, which has taken hold in China in a way that few outside the country truly appreciate. People use WeChat not only to communicate but to

Zuckerberg's overtures to China have already caused some alarm, but he doesn't seem to care.

make purchases, hail taxis, and book doctor's appointments. In America you can say "I'm not on Facebook" and still be a functioning member of society. Avoiding WeChat in China is much harder.

Facebook doesn't have to unseat WeChat in order to succeed. Capturing a relatively small fraction of China's enormous Internet market could bring in significant revenue. The U.S. company should be able to differentiate itself by providing a bridge to the wider world. "WeChat can't compete in that domain," says Cheng, of the Brookings Institution. "Facebook is a global name. WeChat is a Chinese name."

Google could make a similar argument. Despite closing down its Chinese search engine in 2010, Google still sells advertisements in China. Lokman Tsui, Google's former head of free expression for Asia and the Pacific and now an assistant professor at the Chinese University of Hong Kong, says, "If you are a Chinese company and want to reach global audiences, Google is still a really good option."

This past June, Google's CEO, Sundar Pichai, said that he wanted the company to properly return to the country. "We want to be in China, serving Chinese users," he said, speaking at the Code Conference. Tsui says there have been "rumors" that Google's Play Store may enter China (the company declined to comment). Google's Android mobile operating system is wildly popular in China, but the company's ability to extract revenue from that position is limited because the Play Store isn't available.

Google's troubled history with Beijing represents a considerable hurdle, however. "They are certainly not trusted,"

says Kaiser Kuo, formerly director of international communications at the Chinese search engine Baidu and now the host of the Sinica podcast at

China-focused media startup SupChina. Kuo, a well-respected voice on Chinese Internet issues, thinks Facebook's China prospects look promising. "It's likely that they will be in with some of their signifi-

cant services within the coming year,” he says. “There is fairly high-profile engagement with high-ranking Chinese officials and ranking brass at Facebook. You can’t ignore those signals.”

Deal with it

If Facebook does get the green light from Beijing, sticky questions remain about the conditions that would be attached. Would it have to work with a Chinese partner? Would the government require that Facebook store data inside China, making it easier for authorities to access?

Some technical challenges are already clear. Facebook wants to bring everyone into a global network, but Chinese users would be offered very different experiences from those available to their friends in other countries. Sparapani, Facebook’s former policy director, argues that this shouldn’t be hard to do. “You can geo-fence just about anything,” he says. For

example, Facebook already occasionally alters what people in different places around the world can see on the site. In 2015 the company blocked users in France, and only France, from viewing a photo of terrorist attack victims. That same year, a photo of a boy urinating on the Indian flag was made unavailable in India. After receiving a request from the U.K. Gambling Commission, Facebook restricted U.K. access to groups promoting raffles.

Regularly censoring Chinese pro-democracy activists would generate much more controversy. Zuckerberg’s overtures to China have already caused some alarm; his recent Beijing trip triggered tweets tagged with #suckerberg. But Zuckerberg doesn’t seem to care. If he were so worried about accusations of cozying up to China, then he probably would not have asked President Xi Jinping to give his baby a Chinese name

(Xi declined) or so publicly made nice with his propaganda chief.

Zuckerberg likes to say that Facebook exists to “make the world more open and connected.” China is an important part of this plan. Google made a similar argument when it went to China in 2006: It’s better to be there than not. More connectivity is good, even if you have to make a few sacrifices along the way, such as participating in Chinese censorship.

Would Americans buy that argument? Maybe not. Journalists would write scathing articles. Activists and social-media users would unleash derision. U.S. government officials might express concern. But people would keep using Facebook.

Emily Parker has covered China for the Wall Street Journal and been an advisor in the U.S. State Department. She is the author of Now I Know Who My Comrades Are: Voices from the Internet Underground.

Statement of Ownership, Management and Circulation. (Required by U.S.C. 3685). (1). Publication Title: MIT Technology Review, (2). Publication No. 535-940, (3). Filing Date: 9/27/2016, (4). Issue Frequency: Bi-monthly. (5). No. of Issues Published Annually: 6. (6) Annual Subscription Price: \$29.95 (7). Complete Mailing Address of Known Office of Publication: One Main St, 13th Floor, Cambridge, MA 02142 (8). Complete Mailing Address of Headquarters or General Business Office of Publisher: One Main St, 13th Floor, Cambridge, MA 02142 (9). Full Names and Complete Mailing Addresses of Publisher, Editor, and Managing Editor. Publisher: Jason Pontin, One Main St, 13th Floor, Cambridge, MA 02142. Editor: David Rotman, One Main St, 13th Floor, Cambridge, MA 02142. Managing Editor: Tim Maher, One Main St, 13th Floor, Cambridge, MA 02142. (10). Owner: Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139-4307. (11). Known Bondholders, Mortgagees, and Other Security Holders Owning or Holding 1 Percent or More of Total Amount of Bonds, Mortgages, or other Securities: None. (12). Tax Status: The purpose, function, and nonprofit status of this organization and the exempt status for federal income tax purposes: Has Not Changed During Preceding 12 months. (13). Publication Title: MIT Technology Review. (14) Issue Date for Circulation Data Below: July/August 2016. (15). Extent and Nature of Circulation: (a) Total No. of Copies (Net Press Run): Average. No. Copies Each Issue During Preceding 12 Months: 200,426; No. Copies of Single Issue Published Nearest to Filing Date: 196,969. (b) Legitimate Paid and/or Requested Distribution (1) Mailed Outside-County Paid Subscriptions Stated on PS Form 3541: Average No. Copies Each Issue During Preceding 12 Months: 160,876, No. Copies of Single Issue Published Nearest to Filing Date: 159,637. (2) In-County Paid/Requested Mail Subscriptions Stated on PS Form 3541: Average No. Copies Each Issue During Preceding 12 Months: 0, No. Copies of Single Issue Published Nearest to Filing Date: 0. (3) Sales Through Dealers and Carriers, Street Vendors, Counter Sales, and Other Paid Distribution Outside the USPS: Average No. Copies Each Issue During Preceding 12 Months: 11,790, No. Copies of Single Issue Published Nearest to Filing Date: 11,383. (4) Paid Distribution by Other Mail Classes Through the USPS: Average No. Copies Each Issue During Preceding 12 Months: 0, No. Copies of Single Issue Published Nearest to Filing Date: 0. (c) Total Paid and/or Requested Distribution: Average No. Copies Each Issue During Preceding 12 Months: 172,666, No. Copies of Single Issue Published Nearest to Filing Date: 171,020. (d) Nonrequested Distribution: (1) Outside-County Nonrequested Copies included on PS Form 3541: Average No. Copies Each Issue During Preceding 12 Months: 490, No. Copies of Single Issue Published Nearest to Filing Date: 514. (2) In-County Nonrequested Copies included on PS Form 3541: Average No. Copies Each Issue During Preceding 12 Months: 0, No. Copies of Single Issue Published Nearest to Filing Date: 0. (3) Nonrequested Copies Distributed Through the USPS by Other Classes of Mail: Average No. Copies Each Issue During Preceding 12 Months: 0, No. Copies of Single Issue Published Nearest to Filing Date: 0 (4) Nonrequested Copies Distributed Outside the Mail: Average No. Copies Each Issue During Preceding 12 Months: 4,581, No. Copies of Single Issue Published Nearest to Filing Date: 6072. (e) Total Free or Nominal Rate Distribution: Average No. Copies Each Issue During Preceding 12 Months: 5,071, No. Copies of Single Issue Published Nearest to Filing Date: 6,586. (f) Total Distribution: Average No. Copies Each Issue During Preceding 12 Months: 177,736, No. Copies of Single Issue Published Nearest to Filing Date: 177,606. (g) Copies not Distributed: Average No. Copies Each Issue During Preceding 12 Months: 22,689, No. Copies of Single Issue Published Nearest to Filing Date: 19,363. (h) Total: Average No. Copies Each Issue During Preceding 12 Months: 200,426, No. Copies of Single Issue Published Nearest to Filing Date: 196,969. (i) Percent Paid: Average No. Copies Each Issue During Preceding 12 Months: 97.1%, No. Copies of Single Issue Published Nearest to Filing Date: 96.3%. This Statement of Ownership will be printed in the November/December issue of this publication. I certify that all the information furnished on this form is true and complete. Bruce Rhodes, VP of Consumer Revenues and Marketing.

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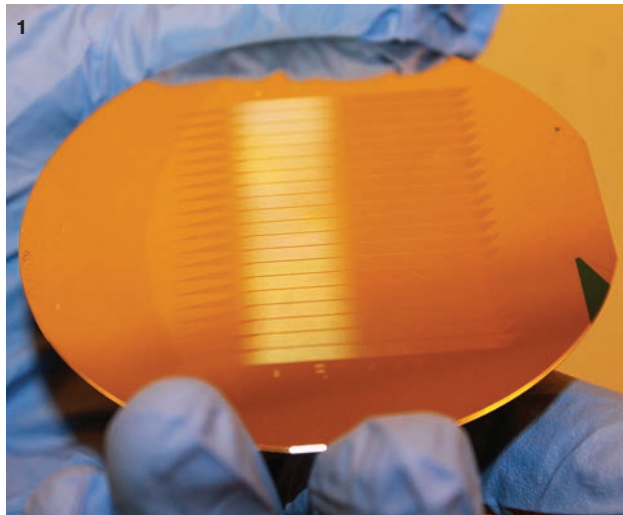
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Demo



Injectable Wires for Fixing the Brain

Novel treatments for neurological diseases might be possible with a flexible mesh that can prod individual brain cells.

By Julia Sklar

Photographs by Joshua Mathews

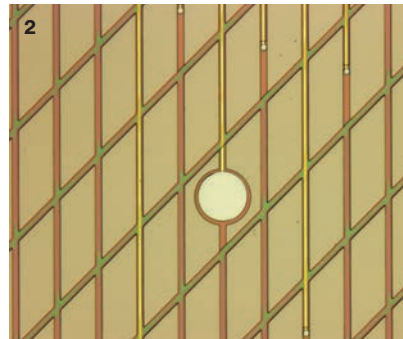
In a basement laboratory at Harvard University, a few strands of thin wire mesh are undulating at the bottom of a cup of water, as if in a minuscule ribbon dance. The meshes—about the length of a pen cap—are able to do something unprecedented: once injected into the brain of a living mouse, they can safely stimulate individual neurons and measure the cells' behavior for more than a year.

Electronic brain interfaces like these could someday be crucial for people with neurological diseases such as Parkinson's. The disease causes a group of neurons in one area of the brain to begin dying off, triggering uncontrollable tremors and shakes. Sending targeted electrical jolts to this area can help whip the living neurons back into shape and stop Parkinson's symptoms.

Today people can undergo an electrical treatment called deep brain stimulation. But it has big limita-

1 The mesh electronics—lines of gold between layers of a polymer—are produced in batches on a silicon wafer.

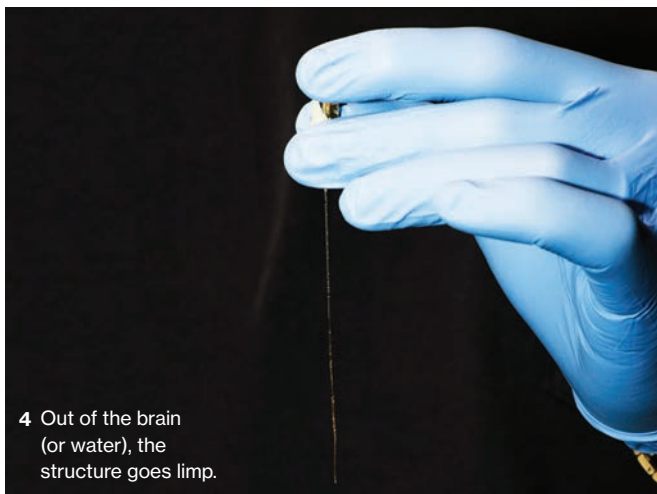
2 This close-up of the mesh shows a pad in the middle that stimulates neurons. Smaller pads measure their activity.



3 As demonstrated here in water, the mesh is extremely flexible once in the brain.



4 Out of the brain (or water), the structure goes limp.



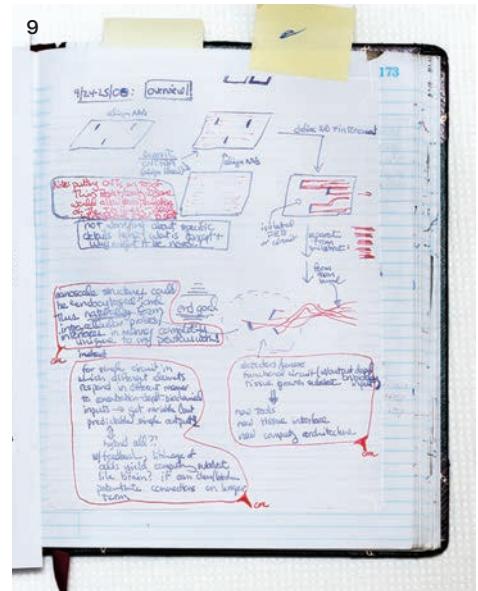
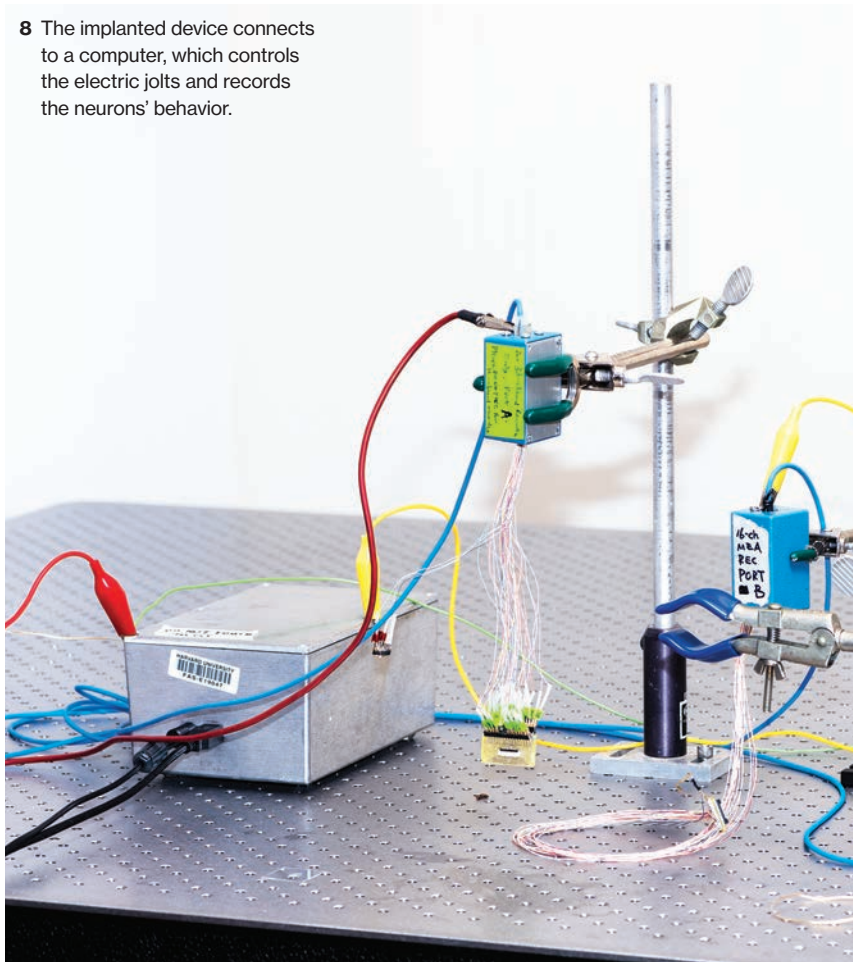
5 The device is flexible enough to be injected by a needle. The net-like structure prevents it from disrupting neurons too much once implanted.



6 The meshes don't tangle or snag easily, even when bunched together in a cup of water.

7 A microscope fitted with a video camera lets researchers watch on a computer screen as a mesh is sucked into a needle.

8 The implanted device connects to a computer, which controls the electric jolts and records the neurons' behavior.



9 A 2007 page from Lieber's notebook shows his first conception of the mesh.

tions. It involves implanting rigid, dense electrodes in the brain. That's far from ideal in such a soft organ: after about four weeks, scar tissue begins to build up. The only way to get the electrodes to work through this tissue is to keep upping the voltage used to excite the neurons. That can be dangerous, and sometimes another surgery is required to replace the implant.

Charles Lieber, a Harvard chemist and nanomaterials pioneer, had a different idea: a conductive brain interface that mirrors the fine details of the brain itself. Just as neurons connect with each other in a network that has open spaces where proteins and fluids pass through, the crosshatches in Lieber's bendable mesh electronics leave room for neurons to fit in, rather than being pushed to the side by a boxy foreign object. "This device effectively blurs the interface between a living system and a non-living system," says Guosong Hong, a postdoc in Lieber's lab.

The extremely flexible mesh, made of gold wires sandwiched between layers of a polymer, easily coils into a needle so it can be injected rather than implanted, avoiding a more extensive surgery. Part of the mesh sticks out though the brain and a hole in the skull so that it can be wired up to a computer that controls the electric jolts and measures the neurons' activity. But eventually, Lieber says, the controls and power supply could be implanted in the body, as they are in today's systems for deep brain stimulation.

The researchers foresee the mesh having many uses beyond Parkinson's. It might help treat depression and schizophrenia more precisely than today's drugs, which bathe the entire brain in chemicals and cause an array of side effects.

First, though, it needs to be tested in humans. Lieber's group is partnering with doctors at Massachusetts General Hospital and will soon begin experiments in people with epilepsy. ■



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Film Adaptation

Since the dawn of the movies, filmmakers have grappled with the techniques of visual storytelling.

“

Swiftly outgrowing the black and white silence of its flickering infancy, the motion picture has within a morsel of time found its tongue and garbed itself in robes of many colors.

And now William Fox, far-seeing showman, announces Grandeur pictures, photographed on a new wide film designed to cover a screen of full stage dimensions.

All this means new cameras and new projecting apparatus, huge screens and a new technique in the studio. While the veteran of the legitimate stage may smile complacently, the celluloid star must learn the art of make-up all over again. Scenery will have to be built with far greater attention to detail than is now the practice, and many of the camera tricks of the past must be discarded because of the new demands of an enlarged screen.

The wide film will permit photography of far greater scope than is possible at present, a fact which offers the director and his man Friday, the art counselor, opportunities for mass effects hitherto unattainable. The new film will do away with the cramped sets now sometimes seen, but the closeup, it is predicted, can be used with an even greater palpitating effect.

The film used by the Fox-Case Company is seventy millimeters wide, exactly double the width of the standard film being used at present. The Paramount-Lasky Corporation is working on a film reported to be fifty-six millimeters wide, while the Radio Corporation of America is said to have decided upon a width between that of Fox and Paramount.

That the wide film and the large screen will eventually come into general use seems assured. For the moment, however, the great need is agreement upon a wide film of standard width. The average exhibitor, still bowed under the financial burden of installing sound apparatus, faces the possibility of being forced to buy several machines to project films of special width.

Claims to the contrary notwithstanding, the wide film, while increasing the scope of motion photography, does not produce stereoscopic effect. The third dimension still remains the ultimate goal of the motion picture, an achievement which, with perfection of color and sound processes, would bring the screen an illusion difficult to distinguish from life itself.”

Excerpted from “Grandeur Movies,” in the December 1929 issue of Technology Review.

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